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THE INSTITUTE OF PETROLEUM

AN Ordinary General Meeting of the Institute of Petroleum was held at 26 Portland Place, London, W.1, on 22 February 1954, the Chair being taken by C. A. P. Southwell, a Past-President of the Institute.

The General Secretary read the minutes of the previous meeting, which were confirmed and signed as a correct record. He then announced the names of the members elected since the previous meeting.

The Chairman, introducing the authors of the paper to be presented, said: The production of crude oil in the U.K. is one of the most important subjects that the Institute of Petroleum could discuss. The paper which follows is therefore especially welcome, and I hope it will be the forerunner of many others of a similar nature. Later, I hope a paper on natural gas will be presented.

The Anglo-Iranian Oil Company has done a great piece of scientific work in searching for oil in the U.K., and we are grateful to Mr Dickie and Mr Adcock for giving us the opportunity of learning the latest developments and the production technique which have been followed in arresting the normal decline of sand oilfields in Nottinghamshire.

The following paper was then presented by Mr Adcock:

OIL PRODUCTION IN THE NOTTINGHAMSHIRE OILFIELDS

By R. K. DICKIE (Fellow) and C. M. ADCOCK

SUMMARY

The development of the Nottinghamshire oilfields is described with particular reference to the evolution of the production arrangements now in operation, and the post-war progress made in water flooding. Some oilfield techniques, developed at Eakring, are described in greater detail than in previous publications.

INTRODUCTION

IN a paper to the IP on "Petroleum in England" C. A. P. Southwell described the war-time search for crude oil, giving details of the discovery of the Nottinghamshire oilfields; and the rapid exploitation of these fields to meet, if only in some measure, the great demand for crude oil production at that time.

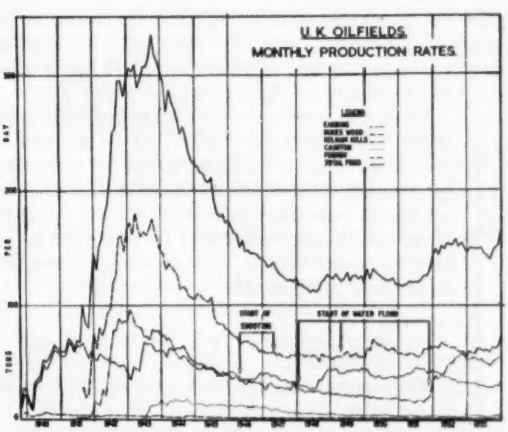

FIG 1

U.K. OILFIELDS MONTHLY PRODUCTION RATES

The geological results of the drilling effort in the search for oilfields in the U.K. have been given in a paper to the Geological Society by Dr G. M. Lees and A. H. Taitt. A mass of exact and new information about the underground geology of the U.K. has been obtained as a result of this work.

This paper continues the account of the post-war development of the Nottinghamshire fields, draws attention to certain techniques that have been developed or adopted in these fields, and describes the efforts made by secondary recovery methods to offset the natural decline of the sandstone fields and maintain production at a worth-while level.

The secondary production methods have had a substantial measure of success; this is illustrated by Fig 1, which shows the annual crude oil production from 1939 to 1953. Production has been well maintained in recent years, and is now running at over 60,000 tons per annum, compared with a fairly close estimate of a present rate of 25,000 tons per annum had secondary recovery methods not been adopted.

RESERVOIR CHARACTERISTICS

The reservoir rocks in the Nottinghamshire oilfields are basal Coal Measures and Millstone Grit series sandstones. The oil has collected in pimples on a general regional uplift in the Carboniferous. This is illustrated by Fig 2, which shows a geological section through the oilfields. The main producing sand is the Rough Rock, the top member of the Millstone Grit. Sand porosities average 10 to 15 per cent and permeabilities are usually only a few tens of millidarcies.

The reservoir sandstones have only short vertical oil columns, varying between 50 and 200 ft. Owing to the low permeabilities, particularly in the Rough Rock, the original connate water was of the order of 50 per cent of the pore space. There is no active

water drive in the Rough Rock, and primary recovery of oil was by dissolved gas drive. The saturation pressure of the gas in the oil was low, being about 390 p.s.i. at Eakring and only about 100 p.s.i. at

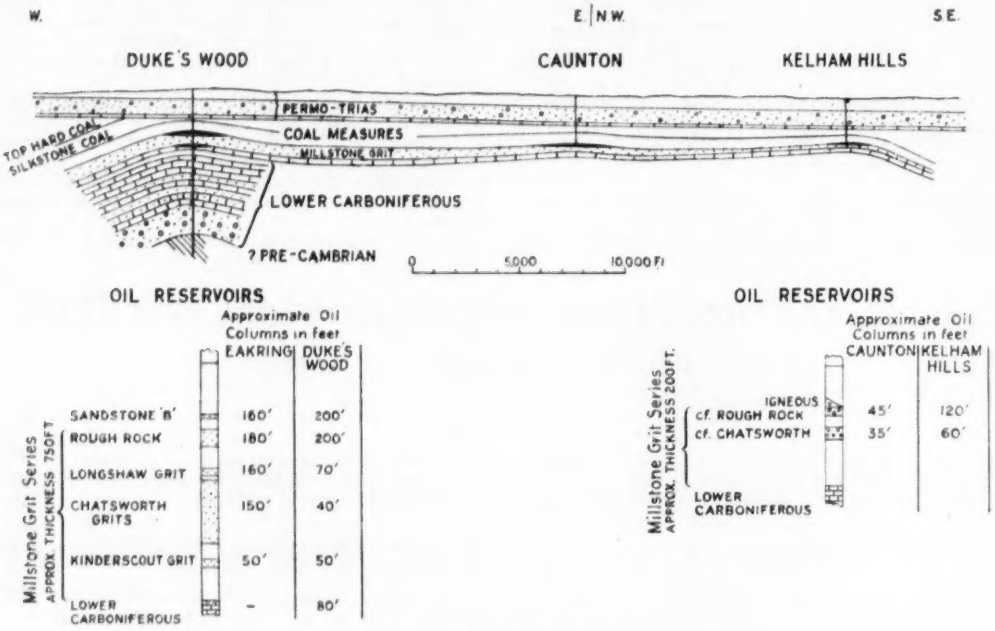

FIG 2

GEOLOGICAL SECTION THROUGH EAKRING OILFIELD AREAS

Kelham Hills. This compares with original reservoir pressures of about 1000 p.s.i. Thus, pressure and production declines were rapid. Fig 3 shows the fall of the Rough Rock pressure at Eakring, and the subsequent change in pressure caused by the adoption of secondary recovery. In the lower producing sands there is an active water drive, and oil production is generally well maintained from these sands until the wells go to water; but as the Rough Rock is the principal producing sand in each field, production from this sand has the dominant effect on the production characteristics of the fields as a whole.

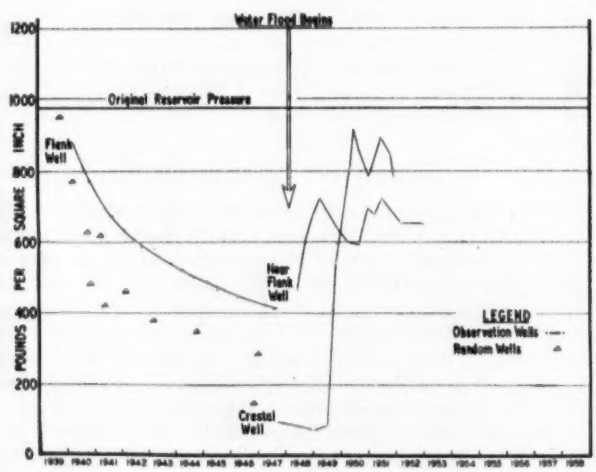

FIG 3

EAKRING ROUGH ROCK, RESERVOIR PRESSURES AT 1700 FT BELOW SEA LEVEL

From the reservoir performance of the Rough Rock it is estimated that about 20 per cent of the oil originally in place would be recovered by primary methods; whilst laboratory experiments on cores indicate that a total recovery of about 40 per cent could be expected by an efficient water drive. It is for this reason that water flooding was introduced in 1947.

DEVELOPMENT OF THE FIELDS

Fig 4 is an underground contour map of the top of the Millstone Grit in the oilfields area on which has been superimposed some topographical detail to show the position of the fields in relation to the surface features. The approximate producing areas are: Eakring and Duke's Wood 600 acres, Kelham Hills 180 acres, and Caunton 50 acres. The number of active producing wells in these fields is at present: Eakring and Duke's Wood 163, Kelham Hills 48, and Caunton 11; these numbers have varied little since the fields were drilled up.

Production is by deep well pump and individual pumping units. Originally these pumped, through a 2-inch buried network, to seven collecting stations where the necessary facilities were established for water separation and oil measurement, but by 1944, when it proved possible to make a reliable estimate of the settled production of the fields, it was decided that a considerable simplification of the surface arrangements was possible. Accordingly, all water separating facilities requiring heat were concentrated at Eakring and gradually all except three collecting stations were eliminated. The three collecting stations are located at Eakring, at the south end of Duke's Wood, and at Kelham Hills. The Caunton wells pump direct to the Kelham Hills collecting station where the oil is mixed with the oil from Kelham Hills and is pumped to Eakring for water separation and measurement.

At the Kelham Hills and Duke's Wood collecting stations the whole of the fluid handled is passed through knock-out tanks to separate as much water as practicable from the oil and emulsion before it is pumped to the treaters. When the pumping distance is short, as it is for the Eakring and some of the Duke's Wood wells, the production is pumped direct to the treaters, through a water knock-out device operating under the pipe-line pressure. The dry oil from the treaters is stored in tanks at the Eakring collecting station. The oil is then pumped to the Bilsthorpe siding, where it is measured in the 400 tons Royalty tanks. From the siding the oil is pumped into rail tankers for transport to the refinery at Pumpherston in Scotland. The oils from Kelham Hills and Caunton are kept separate from the oils from Eakring and Duke's Wood, as these two groups of areas are operated under different mining licences.

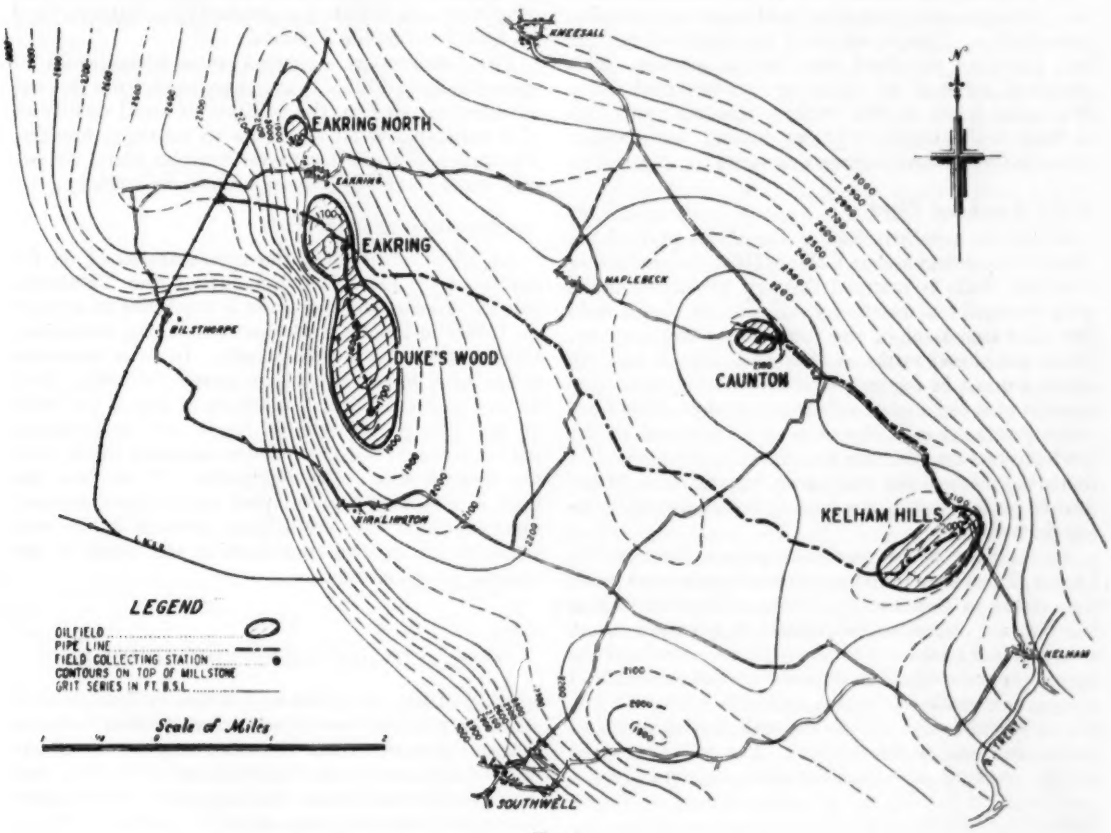

FIG 4

UNDERGROUND CONTOUR MAP OF THE TOP OF THE MILLSTONE GRIT IN THE OILFIELDS AREA

PRODUCTION PLANT

The following is a more detailed description of the operation of individual plant items:

Deep Well Pumps

There are some 220 pumping wells in the Nottinghamshire oilfields, the wells being about 2000 feet deep. Conventional deep well plunger pumps are

used, most of them being 2-inch tubing liner pumps using hardened steel plungers. Plain 2-inch tubing and $\frac{5}{8}$-inch rods are used, and the pumps are operated by electric motor-driven unit pumpers of various types. The capacity of the pump is matched to the capacity of the well by conventional methods of altering the speed and stroke. If the well capacity is small, a further reduction in pump capacity is achieved by intermittent pumping, controlled by electric time switches.

At Eakring and Duke's Wood wax is deposited in the tubing whilst pumping, and must be removed periodically. This is achieved by electrical heating and pumping the fluid wax out at surface. This electrical method of dewaxing is described later. Wax also forms in the surface pipelines, and this is dealt with satisfactorily by passing " go-devils " through the lines at intervals dictated by experience.

Water Knock-out Plant

It will be recalled that at the south end of the Duke's Wood field and at Kelham Hills the production from the wells is pumped through knock-out tanks with conventional overflow arrangements, to maintain the oil–water level in the tank about half-way up. These are closed tanks so that both the oil and the water are not in contact with the air, but they only operate at a few inches of water pressure. The total water produced is of the order of 75 per cent of the fluid production, and the knock-out tanks succeed in removing most of the free water, leaving some 30 per cent to go forward in the fluid to be separated in the heater treaters.

At Eakring, where the wells pump direct to the treater, it has been found necessary to remove as much free water as possible before the production enters the treater, otherwise the treater is overloaded. A conventional knock-out tank would not withstand the higher pressures that are imposed on this system, and a separator made of 15-inch casing is used. This is not so efficient as a knock-out tank, but it serves to relieve the load on the treaters. The water removed is kept air-free and is used for water injection.

Emulsion Treaters

Four heater-treaters are installed at the Eakring collecting station and these treat the whole of the fluid production from the fields. They are of American design, three of 8-ft and one of 6 ft-diameter and all about 30 ft high. Originally they were designed to operate on natural gas, but of recent years the amount of natural gas available in the field has so declined that an alternative mode of heating had to be adopted. Fuel oil could have been used instead of gas, but the method of firing into a simple U-shaped fire tube was not efficient; and it was decided that it would be more economical to convert the fire tubes to steam heating. This was done by connecting the steam line to the top end of the fire tube, and blanking off the bottom end. The underside of the lower limb of the fire tube was perforated with $\frac{1}{2}$-inch holes so that condensate and live steam could be discharged into the treater. Steam is admitted to the fire tube through a steam reducing valve adjusted to pass 1000 lb steam per hour to the larger treaters, and 500 lb/hr to the smaller treaters. These amounts of steam are required to develop the full ratings of the treaters, but the actual quantity of steam used is controlled by thermostats. The whole of the available heat of the steam is used in heating the fluids in the treater, and the condensate is disposed of with the water separated from the oil. Steam, which in any case is required for other purposes at Eakring, is raised by a battery of fuel oil fired " Economic " boilers.

The treaters are operated at a temperature of approximately 170° F, water separation from the wet oil being assisted by the addition of small quantities of a sulphonated oil to act as an emulsion breaker. The outlet oil from the treater contains about 0·5 per cent water, and this is acceptable to the refinery.

Oil Measurement in the Field

As previously stated, the measurement of oil for royalty purposes is carried out at the Bilsthorpe siding. In the field, however, a check has to be kept on individual wells, and this is done by measuring them periodically in field tanks. In some instances it has been found possible to group the wells, three or four to a tank, which is set up at one of the wells of the group. Production lines are so arranged that any well in the group can be switched to the tank for measurement. On completion of the test the fluid is measured and sampled and is then pumped away through the production network by a ram pump which can be connected to the beam of the nearest pumping unit.

SECONDARY RECOVERY SCHEME

Early in the life of the field it was evident that oil recovery was likely to be low unless assisted by some external means. After the war, the merits of gas repressuring and water injection were studied, and it was decided that water flooding would be the more satisfactory method of secondary recovery.

Accordingly, a pilot scheme was started in 1947 pumping about 10,000 gal of water per day to a well at Eakring, which had been drilled below oil–water level in the Rough Rock early in the life of the field and was in use as a pressure observation well. A second well was provided, also in the water zone of the Rough Rock, at a distance of about 800 ft to act as an observation well. The results of this test were very satisfactory; it was proved that the injection well would take the amount of water required continuously with little decline and that the water was distributed laterally fairly rapidly. No measurable increases in production took place, but these were not expected.

The results of the pilot scheme provided a reasonable basis for the design of the Eakring injection scheme.

It was decided to adopt the "closed system" of water injection, as the existing production arrangements were such that all separated water could be readily kept out of contact with air, and "make-up" water could be obtained free from dissolved oxygen. This simplified the design of the system, as no water treating plant and settling ponds had to be constructed. Simple filtration and threshold treatment with Calgon was sufficient to provide a satisfactory injection water. In practice it has been found that some corrosion takes place in the system, but this has not been serious enough to call for special measures to combat it.

The disposition of the injection wells had also to be decided. In most secondary recovery projects in sand

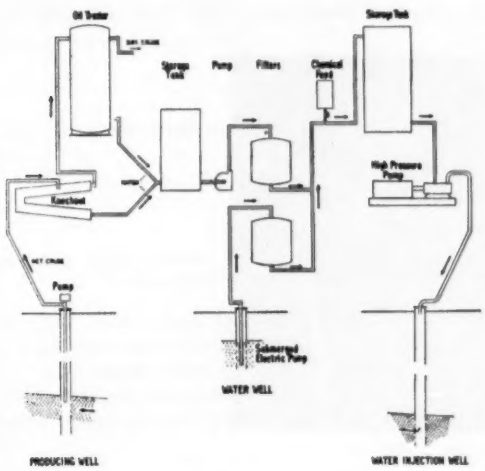

FIG 5
WATER FLOOD SCHEME

fields in the U.S. pattern flooding is adopted, which, in a typical case, means that there are as many injection wells as production wells. It is usually possible, however, to drill the injection wells cheaply, as much of the casing can be eliminated and the wells completed with injection tubing. This was not possible at Eakring, as a full string of casing has to be cemented to the base of the coal measures to protect an active coalfield. It was therefore decided in the first place to inject only into wells drilled around the periphery of the field and observe the effect. In the event, this policy has proved to be successful and has been adopted in the later floods at Duke's Wood and Kelham Hills.

The layout of the Eakring water flood plant is shown diagrammatically in Fig 5. The system is simple and has operated satisfactorily for eight years. Similar systems, differing only in minor details, have been installed at Duke's Wood and Kelham Hills.

Air-free water from the knock-out tank and treater flows to a storage tank, from which it is pumped by a centrifugal pump through a pressure sand filter to the clear water storage tank. The make-up stream of air-free water is pumped from a well about 500 ft deep, drilled into the Bunter sandstone. This water is pumped, when required, by a submerged electric pump directly through a second sand filter to the clear water storage tank. The capacity of the latter is about 4000 gal, and it serves as a suction tank for the high pressure injection pumps.

The following are details of various plant items:

Sand Filters

Vertical pressure sand filters of standard pattern are used. These are 4 or 5 ft in diameter, depending upon the amount of water handled. It has been found that the 5-ft diameter filter will handle about 80,000 gal of water per day. These filters have to be backwashed once a day, and facilities are provided for backwashing at the rate of about 10 g.p.m/sq. ft. of filter bed area. The backwash water is drawn from the clear water storage tank, and is discharged to waste, taking with it the foreign matter accumulated in the filter bed during the previous 24 hr.

Auxiliary Water Wells

Make-up water wells have been drilled into the Bunter sandstone in each of the three fields. The wells are lined with 10-inch casing, cemented into the top of the Bunter sandstone. Submersible electric pumps supply the make-up water automatically when required by means of pressure-operated switches in the clear water storage tanks. Recently, due to the centralization of water separating facilities at Eakring and the increased amount of water produced with the oil, the Bunter water well at the Eakring injection plant has been little used. In the other plants, however, a substantial proportion of the injection water is from the auxiliary water wells.

High-pressure Water Injection Pumps

Since pumps for water injection duty are not in standard production in the U.K., some difficulty was experienced in obtaining suitable pumps when the Eakring injection scheme was being prepared. However, four pumps which had been used in the Pluto scheme for pumping petrol to France were purchased. These are horizontal triple ram pumps with an output of 50,000 g.p.d. at a pressure of 1500 p.s.i., and appeared to be well suited for the duty required.

Electric drive was arranged for these pumps by 75-h.p. motors. In use, the pumps have not been wholly satisfactory, as they suffer from a number of defects inherent in their war-time design. However, on the whole, the Pluto pumps acquitted themselves well, and made it possible to begin a full-scale water flood at Eakring perhaps a year earlier than would have otherwise been the case. Two were used at Eakring and two used later when the Duke's Wood scheme was installed.

For the Kelham Hills field vertical triplex ram pumps were ordered, such as are widely used in the U.S.A. for this purpose. The only size available in the U.K.

has a capacity of 35,000 g.p.d. at a discharge pressure of 1700 p.s.i. These pumps run at 350 r.p.m. and are driven direct by vee belt from the electric motors, so eliminating gearing. They are very easily maintained, as the pump components are light, and the rams and valves very accessible. It is essential, however, to provide at least a 10-ft head of water pressure on the suction, and this is done at Kelham Hills by elevating the clear water storage tanks.

Injection Wells

The injection wells are either wells which have been specially drilled for this purpose, or are production wells which have gone to water. The wells are lined mostly with 6⅝-inch casing, leaving the Rough Rock as the injection horizon. Fig 6 shows the wellhead arrangement at an injection well and the provision made for metering the water. Injection capacities vary from 20,000 gal or more, to 1000 gal or less, per day per well.

The pressure in the main which feeds the injection wells is about 1200 p.s.i. Well intake capacity is restricted, where necessary, by inserting an orifice plate in the inlet to some of the higher capacity wells. Some of the wells have required cleaning, but generally the hole maintenance work has been remarkably small. No casing failures have occurred.

FIG 6

WELLHEAD ARRANGEMENT INCLUDING PROVISION FOR METERING THE WATER AT AN INJECTION WELL

WATER FLOODING AND ITS RESULTS

Water flooding began at Eakring in 1948, at Duke's Wood in 1949, and at Kelham Hills towards the end of 1951. Yearly productions expressed as tons per year are given in Fig 7, and the effect of water flooding is immediately apparent. This is a composite diagram; and the annual productions without water injection have been determined from the log–log production decline graphs for each oilfield area. For instance, Fig 8 shows the log–log graph for the Kelham Hills field. It will be noted that annual production, apart from Secondary Recovery, can be estimated with reasonable confidence.

Brief details of the water flood schemes are as follows:

Eakring and Duke's Wood

A structural contour map on the Rough Rock in ft below sea level is given in Fig 9 for the Eakring and Duke's Wood fields. The many small faults are in general no barrier to the progress of the flood. In all, there are twenty-three water injection wells and some 163 production wells. The injection well spacing is usually from 800 to 1000 ft, depending on sand conditions.

The first marked oil production increase took place in the Eakring field from August 1948 (see Fig 7) onwards, and production rates from the field were doubled by the end of that year. There was some falling off in production in 1950 due to a decrease in water injection, but this was rectified the following year by installing a second Pluto pump. It is estimated that by the end of 1953 the additional production gained by secondary recovery was 40,000 tons.

At Duke's Wood the increase in production was less spectacular than at Eakring. The production gained by secondary recovery to the end of 1953 was only 24,000 tons on a larger field potential. The arrest of the production decline from 1947 to 1949 was due to shooting about one-third of the production wells each year. This technique is described later.

Kelham Hills

Fig 10 shows a structural contour map on the Rough Rock. There are in all eight water injection wells and forty-eight production wells. Most of the injection wells were originally production wells which have gone to water and are located above original oil–water level. In this field there was a remarkably rapid response to water injection. Injection started in November 1951, and by the end of the year there was a substantial increase in production, which was soon

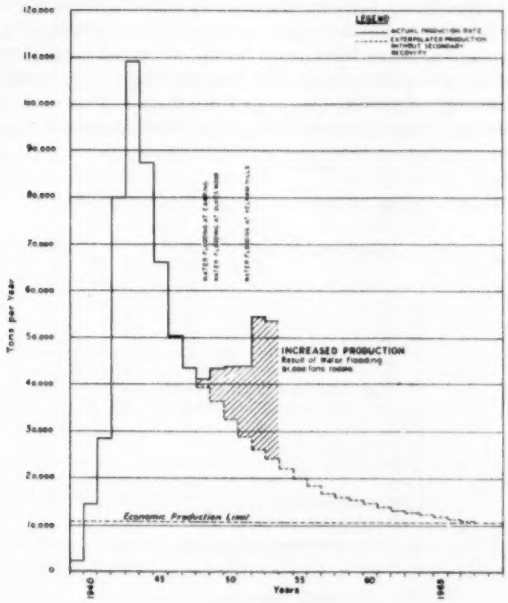

FIG 7

EAKRING, DUKE'S WOOD, AND KELHAM HILLS, EFFECT OF WATER FLOODING ON PRODUCTION

more than three times the rate prior to injection. This high rate was maintained throughout 1952 and 1953. The rapid reaction to water injection is attributed to peripheral thinning of the reservoir rock. The production gained by the end of 1953 was 27,000 tons.

Conclusions

Under primary recovery conditions the average production rate per well in the Nottinghamshire oilfields had fallen by 1948 from some 10 tons to ½ ton per day. If the capital sum, which has been spent on

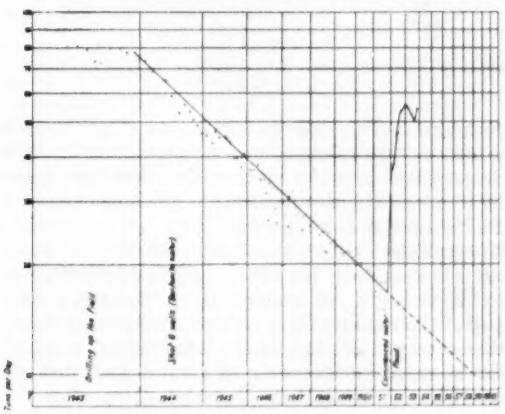

FIG 8

KELHAM HILLS AVERAGE MONTHLY OIL PRODUCTION RATES—TONS/DAY

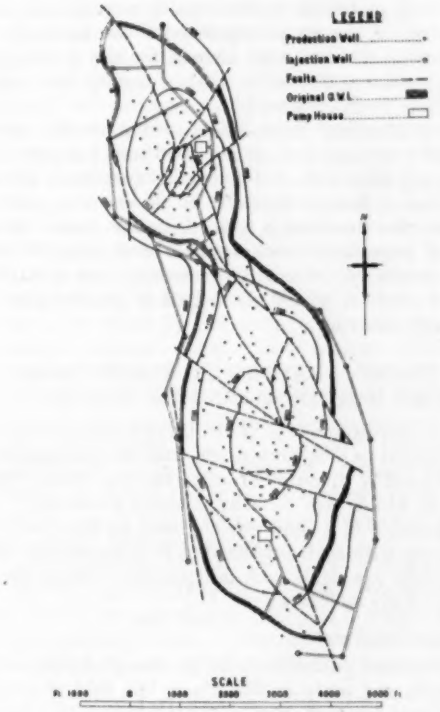

FIG 9

EAKRING AND DUKE'S WOOD, ROUGH ROCK CONTOURS BELOW SEA LEVEL

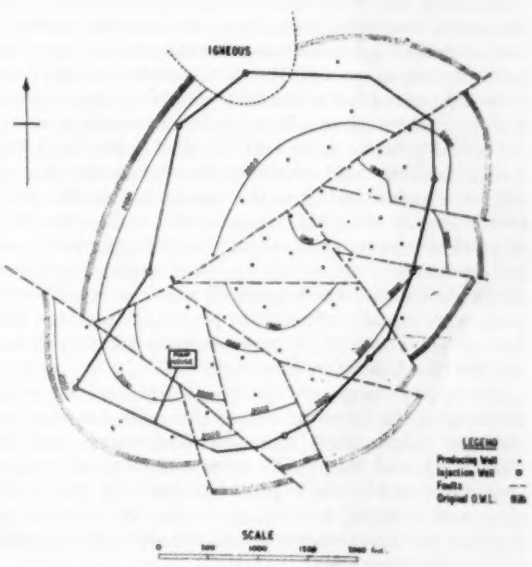

FIG 10

KELHAM HILLS, ROUGH ROCK CONTOURS BELOW SEA LEVEL

the drilling of fifteen water injection wells and the installation of the plant required for the water flood operations, had been used instead for the drilling of infilling production wells, a total of twenty-four wells would have been obtained.

The production from these wells would have averaged ½ ton per day, or say 4000 tons per year for the twenty-four wells. Decreasing quantities of oil would have been obtained in succeeding years. Whereas the production gained in six years as a result of secondary recovery has been some 91,000 tons of crude oil. Current production rate is 60,000 tons per year, of which about half is attributable to secondary recovery.

TECHNIQUES ADAPTED TO CONDITIONS IN THE NOTTINGHAMSHIRE FIELDS

In the operation of the fields, three techniques have been adapted to local conditions, and this has entailed a considerable amount of experimental work, the results of which may have application elsewhere. It is not possible in a short review, such as this, to deal thoroughly with each subject, but it is hoped that the main points are dealt with adequately. These three techniques are as follows :

Well Shooting Practice

Well decline, particularly in the Rough Rock wells, was rapid, and early in the life of the field shooting of the sands by high explosive was tried with a view to increasing the general level of production. In two particulars, namely the method of stemming the shot and the method of cleaning out the hole before and after shooting, considerable experimentation was carried out to determine the most satisfactory method.

Broadly, two methods of stemming were tried, fluid stemming and solid stemming. In the first the hole is filled with fluid to surface after the shot is placed in position; in the second the shot is confined either by several hundred feet of gravel or similar material or by a short cement plug. When solid stemming is used, the usual practice is to bail the well down until the well is making fluid, ensuring that when the shot is fired flow is induced from the formation into the well, so tending to clear the pores of the rock. The use of solid stemming gave substantially higher increases in production, other things being equal, and was adopted. The various methods used for solid stemming were equally effective in confining the shot, but a short solid cement plug causes least delay in cleaning out the hole after shooting.

As rotary tools are used exclusively, the only variable in the cleaning out of the wells was the circulating fluid. Mud, bentonite and water, and oil were used, and the results were compared in a sufficient number of wells to prove conclusively that wells shot and cleaned out using oil as the circulating medium gave greater increases in production than any of the other methods.

This shooting technique is illustrated by Fig 11 and is as follows : the hole is cleaned out to bottom using oil circulation. It is then filled up to the bottom of the formation to be shot with cement asbestos pipe. The explosive, polar blasting gelatine, is loaded into sheet metal containers, each 6 ft long having conical ends. A charge of 400 lb, the largest used, will cover a 30-ft interval in a 7¾-inch hole, or a 60-ft interval in a

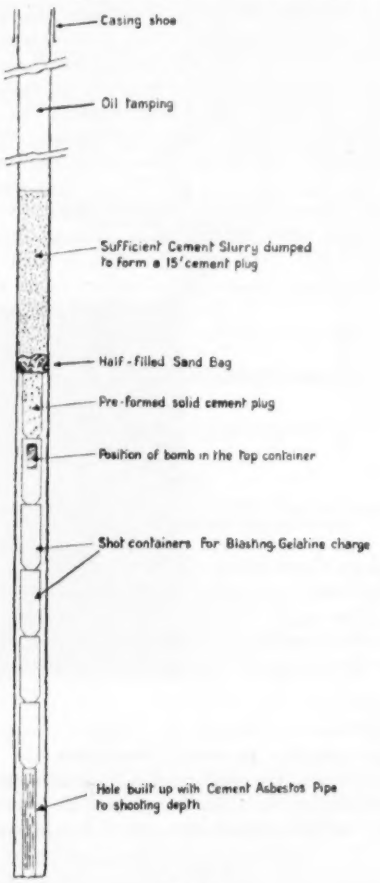
Casing shoe
Oil tamping
Sufficient Cement Slurry dumped to form a 15' cement plug
Half-filled Sand Bag
Pre-formed solid cement plug
Position of bomb in the top container
Shot containers For Blasting Gelatine charge
Hole built up with Cement Asbestos Pipe to shooting depth

FIG 11
GENERAL ARRANGEMENT OF A SHOT IN THE OPEN HOLE OF A WELL

5⅜-inch hole. The loaded containers are run in on a wire line and are released by a detaching hook. The containers nest into one another, and thus the charge is built up to the desired length. A time bomb is placed in the top container.

To stem the charge, a precast cylinder of cement about 3 ft long, together with a half-filled sandbag on top of it, is first of all released by the detaching hook on top of the last explosive container. Cement slurry is then dumped on top of the sandbag by a dump bailer in sufficient quantity to form a 15-ft cement plug. The oil in the hole is bailed down after the stemming is in position, leaving only a few hundred feet of oil in the hole to ensure that the well produces freely when the shot fires.

The principle of the delay switch and the design of the bomb were described in a paper to the IP in 1946 by J. F. Waters.

At Eakring and Duke's Wood this shooting technique was successful, and, on an average, resulted in doubling the production of the wells shot. When one-third of the wells was shot per year, the production decline of the field was arrested. This is illustrated by Fig 12, the log–log production decline graph for the

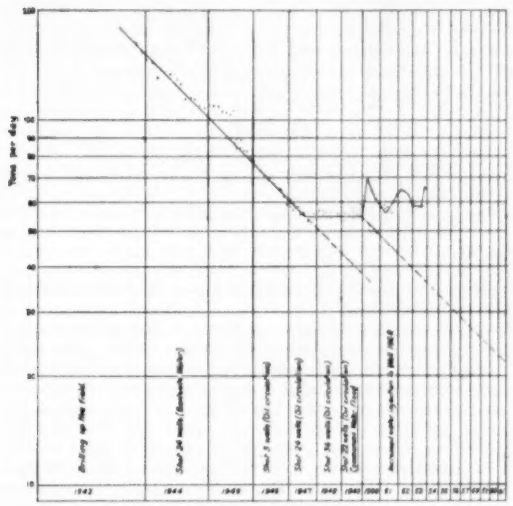

FIG 12

DUKE'S WOOD AVERAGE MONTHLY OIL PRODUCTION RATES—TONS/DAY

Duke's Wood field. Re-shooting was less effective, and it was soon clear that the production decline could not be offset by routine shooting after all the wells in the field had been shot once. This shooting technique has also been used to increase the intake capacity of water injection wells.

Electrical Dewaxing of Pumping Wells

Pumping wells at Eakring and Duke's Wood tend to wax up in the upper part of the tubing. This caused much trouble in the early days of the field and necessitated the pulling of rods and tubing at frequent intervals. However, in June 1940, a description of a method of electrical dewaxing appeared in the U.S. technical Press, which seemed to be well suited to conditions at Eakring. The technique, adapted to local conditions, was tried out and was most successful. Electrical dewaxing is now a routine procedure, and it has solved the waxing problem in well tubing.

The well tubing is insulated from the tubing head by a plastic bush, and from the casing by hardwood insulators spaced 40 ft apart by being strung on every second tubing joint. At about 1200 ft from surface a " contactor " is inserted in the tubing string. This " contactor " is in effect a tubing coupling to which are welded four steel bows which make electrical contact with the casing. The source of the D.C. current is a motor generator set mounted on a lorry. The 86-h.p. A.C. motor of this set is readily connected by a high duty plug and socket to the 440-volt three-phase power line to every well. The D.C. generator has a rating of 800 amperes at 55 volts.

For dewaxing, the well is shut down, the lead line disconnected, and the polished rod, supported on a clamp, disconnected from the pumping unit, thus isolating electrically the tubing from the casing and earth. One cable from the generator is clamped to the tubing, and the other to the casing head; then the set is started up and run for about an hour. The current passed through the tubing-casing circuit is readily controlled by the voltage adjustment on the generator control panel. The current heats the tubing and rods sufficiently to melt the wax in contact with them, and to dissolve a proportion of the remainder of the wax in the tubing. Thus at the end of the period of dewaxing it is only necessary to reconnect the polished rod to the pumping unit and to start pumping to bring the wax to surface. The whole operation takes only two to three hours, and several wells can be dewaxed per day.

A regular programme is in force for dewaxing wells at intervals dictated by experience. Some few will have to be dewaxed weekly, but most at longer periods of up to several months. Of recent years no dewaxing has been necessary at Kelham Hills or Caunton.

Fluid Levels by Echometer

As individual well productions are measured at intervals of about a week only, and as these measurements will not necessarily ensure that wells are properly " pumped down," an " Echometer " was obtained from the U.S.A. This instrument operates by recording the time of firing a shot in a chamber attached to the wellhead, and the time of arrival of the return wave at surface, after having been reflected from the fluid level in the annular space between the tubing and the casing. Multiple reflections are also recorded from other obstructions in the annular space, such as tubing collars, liner tops, etc. On a good record these latter reflections can be identified fairly easily after a little practice, and from them the depth of the fluid level can be deduced, provided the well records are accurate. It was found that calculations based on sound velocity are unreliable owing to the difficulty of deducing an accurate sound velocity from the well data.

The original echometer suffered from a number of defects which detracted from its accuracy, slowed up its operations, and rendered it incapable of obtaining reflections in annular spaces of small cross-sections. These, among others, were: (*a*) short microphone life caused by the shock of firing the cartridge; (*b*) fouling of the electrical connexions by burnt powder; (*c*) lack of frequency control of the sound waves generated by the blank cartridge, much of the frequency range being unwanted; and (*d*) slowing down of the recording paper feeding motor when receiving high amplitude sound waves, so giving an inaccurate

time scale. Accordingly, efforts were made throughout the years the instrument was in use to eliminate these defects; and in the echometer now in use the hot wire microphone is the only piece of apparatus of the original echometer which has survived. Various forms of microphone were tried, but none proved as suited to the conditions as the original one.

In the present instrument the sound waves are formed by striking a rubber diaphragm. This generates waves of a range of low frequencies which give satisfactory reflections, even in wells with annular spaces of small cross-sectional area. The elimination of unwanted waves, which were produced when a shot was fired, gives a clear and unambiguous record. An added advantage of this method of generating waves is that records can be made in rapid succession, varying the strength of the blow until a clear reflection is obtained, so speeding up the operation very considerably. The recording instrument is a modern single moving pen recorder using electrolytic paper. The speed of the paper is accurately controlled, and its speed can be checked by a timing device.

The recording instrument is mounted in a van, and about thirty wells can be surveyed per day, compared with ten by the original instrument.

ACKNOWLEDGMENTS

The authors wish to acknowledge with thanks the permission of the chairman and directors of the Anglo-Iranian Oil Company Ltd. to publish this paper and the ready assistance and advice of the manager and staff of the D'Arcy Exploration Company Ltd. at Eakring in its preparation.

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DISCUSSION

H. C. Lack: It is a tribute to the organization, which has played such a large part in developing the petroleum resources of the Middle East and which is actively concerned in producing, refining, and marketing oil on a vast scale in all parts of the world, that it has, with equal energy, devoted its attention and the whole wealth of its experience to the discovery and production of oil in the U.K. The development of the Nottinghamshire oilfield has been anxiously followed from the day when their existence was proved by a teaspoonful of brown, smelly liquid in the driller's teacup to the present-day production figure, and especially the wartime peak of over 100,000 tons per year.

There have, of course, been teething troubles, and the authors of the present paper and their colleagues can doubtless recall nights spent in pacing the derrick floor waiting for things to happen. But the simile should not be carried too far, for whereas well-behaved human infants are supposed " to keep it down," infant oilfields are supposed " to bring it up."

Mr Dickie and Mr Adcock have given us a very clear picture of the work and research that have been going on steadily for more than a decade in the Nottinghamshire fields, where the casual observer may see only green fields and a few cows but the oil man cannot fail to notice the pumping jacks. I was particularly impressed with the success that has been achieved in the scheme for secondary recovery. A water flood in the usual manner from edge to centre has been devised and brought into operation, and is shown in the paper to have yielded economic returns of many times its investment and running costs. Instead of a decline to a present estimated rate of 25,000 tons per year, the production rate now stands at about 50,000 tons per year.

In this connexion, I suggest that it would be of considerable interest to include with the information given in the paper further statistics on the water flood project, such as were stated in a paper last year by Messrs Comins and Adcock, read before the French National Petroleum Congress at Toulouse. The figures then given related to the situation at 31 December 1952, and were as follows:

Total daily water injection rate	230,000 gal
Total daily water production rate	170,000 ,,
Total water injected	277,000,000 ,,
Total fluid production	485,000,000 ,,
Total oil gained	62,000 tons
Total oil produced	711,000 ,,

It would be of great interest if these figures could be brought up to date by giving corresponding quantities as at the end of 1953.

I would now like to put a question to the authors concerning pumping pressures at injection wells. The productivity index of a well relates the quantity of fluid produced to the draw-down of formation pressure necessary to cause the flow. Now, as D'Arcy's law makes no mention of direction of flow, the same figure might be expected to relate the quantity of injection fluid to the rise of pressure necessary for the formation to accept that fluid. I should like to ask whether any observations have been made tending to confirm or disprove such an assumption. A correction would, of course, be necessary to allow for the different viscosities of water and oil.

In his paper entitled " Our Unproduced Reserves " read before this Institute in September 1951, Dr Morris Muskat referred to a means of reducing the residual oil saturation by the injection of miscible solvents, mentioning especially liquid petroleum gas (LPG). Other investigators have suggested the use of detergents or viscosity reducers. I would like to ask whether the authors have considered or tried any of these or other similar means of increasing recovery.

Mr Adcock: As requested by Mr Lack I have brought up to date the statistics on the water flood project. The situation at 31 December 1953 was as follows:

Water Flood Statistics—Nottinghamshire Oilfields to 31 December 1953

Water flooding in operation	Eakring	6 years
	Duke's Wood	5 years
	Kelham Hills	2 years
	Caunton	Due to begin during 1954
Wells drilled for water injection		15
Production wells (gone to water) taken over for water injection		17
Hence, total number of water injection wells		32
Total number of pumping wells		214
Total daily water injection rate		283,000 gal
Total (all fields) daily water production rate		193,000 gal
Total (all fields) daily fluid production rate		236,000 ,,
Cumulative fluid production from Notts. fields		574,000,000 ,,
Cumulative water injected into Notts. fields		365,000,000 ,,
Cumulative oil production from Notts. fields		791,000 tons
Cumulative oil gained from water flooding		91,000 ,,

With regard to Mr Lack's first question as to whether D'Arcy's law can be related to the quantity of water injected into a well, we have not made any specific experiments to test this point. We have, however, carried out formation tests on the flank wells which have been drilled for water injection. Roughly, we would say that the water injection capacities estimated from the production rates in these tests have been achieved in practice; so that we have no reason to believe that D'Arcy's law does not apply equally to water injection as it does to fluid production.

On the question of reducing the residual oil saturation by the introduction of chemicals along with the injection water; we have carried out a certain amount of work using surface tension reducing agents, such as Calsolene oil, and Byprox. With both these chemicals a small increase in oil production is obtained, but the results are not economic. We found that the cost of Byprox (or Calsolene oil) was as much as the value of the extra oil gained. Probably most of the chemical used is lost by adsorption on to the sand surfaces, and not much chemical is available for additional oil recovery. I would also consider that the injection of liquid petroleum gas to reduce residual oil saturation, mentioned by Mr Lack, would not be an economic operation. Recently, in the American press, the introduction of carbon dioxide into the injection water has been recommended to increase the oil recovery; but in this case also, I think that the value of the additional crude oil recovered would not be much greater than the value of the carbon dioxide used. Thus the economic aspect of the use of chemicals to increase oil recovery is most important; and one which has to be borne constantly in mind when trying out new techniques.

Dr G. M. Lees: As one of the founder members of this society of English producers, it has given me great pleasure to hear the latest developments in the exploitation of the Nottinghamshire fields. Eakring was discovered in May 1939; and like most oil men we were full of great hopes and enthusiasm; we had no measure of how big the field at Eakring would prove to be, but in our optimism we imagined that it was going to be very much bigger than eventually it has turned out. Our hopes flagged somewhat; until we began to find new fields at Duke's Wood, Kelham, and Caunton, and then the need during war-time was so great, that we started a wholesale exploration programme in the country north and south and east of Eakring itself, carried out under the very able direction of Mr Southwell. By seismic methods we found a number of promising structures, and optimism began to rise again. We thought we were going to repeat Eakring several times over and we drilled a large number of wells resulting only in one disappointment after another. A number of near misses kept us hoping, and we persevered. A sad disappointment was at Nocton, south of Lincoln, where we got a little oil from the carboniferous limestone, it was a main structure, but had been so deeply eroded in pre-Permian time that the cover rocks had been removed, leaving only a little residual oil. After its wartime peak production declined, rapidly, but later, as a result of secondary recovery schemes initiated by Messrs Comins, Dickie, and Adcock, the decline has not only been arrested but production has increased. The graphs show the net gain is very satisfactory, and although the scale of operations is small, it is an outstanding demonstration of the benefits of secondary recovery. Now, we have just had another success at Plungar. It is the first discovery since 1943—that is to say, after ten years of effort, involving drilling a large number of exploration holes, we have at last " rung the bell " again. We hope that Plungar will develop into a field at least the size of Eakring, and as optimism can never be completely restrained, we hope for something very much larger, at least it gives us a footing in a new area, about 25 miles south of Eakring, of somewhat different geological circumstances.

In the meantime, the secondary recovery goes on. Mr Adcock has said that the total production is already about 800,000 tons; I wonder if he could add to his statistics a figure of his estimate of how much remains, before the production line reaches what he calls the economic limit.

Also, it would be interesting to know from him the percentage recovery that he expects to achieve by secondary recovery, and how that compares with what it would have been under ordinary recovery without water injection.

Mr Adcock: Dr Lees, I believe, knows that an investigation has been carried out at the A.I.O.C. Research Station at Kirklington Hall to assess the quantity of oil recoverable from the Nottinghamshire oilfields. Under primary recovery alone, we could expect to produce no more than 20 per cent of the oil in place. With the application of water flooding it is hoped to double this recovery; so that in all, 40 per cent of the oil in places would be obtained. These are unavoidably very rough figures; but they mean in effect that the economic recovery by primary production methods alone would be about 800,000 tons, and that with water flooding another 800,000 tons can be expected. That is to say we have now produced about half the recoverable oil; but this is only an approximate guess, and is very far removed from anything like a firm estimate. The actual limit for the economic production will, of course, be dependent on the value of the crude oil in relation to costs by the time this stage is reached.

It is very difficult to reply to Dr Lees' question whether it would have been more advantageous to have begun water flooding operations as soon as the limits of the Nottinghamshire oilfields had been determined.

All that can be said with any certainty is that by beginning the water flooding operations about half-way through the normal primary life of the fields very successful results have been obtained; and whether better results would have been achieved by starting earlier is not an easy matter to decide. From the practical standpoint there is not much chance of trying the experiment, particularly for peripheral flooding. Almost inevitably production is drawn from a field which is being delimited by drilling; and no flank well injection scheme can be planned until the size of the oilfield is known.

P. Evans: Could Mr Adcock say whether he has found an increasing reluctance of the sand to take the injected water, after allowing for changes in differential pressure. Also, is there any evidence that waxing effects in pipelines are more troublesome in cold weather than in hot?

Mr Adcock: In general there does not seem to be a decline in the intake capacities of the injection wells, apart from the normal decline resulting from the build up of the reservoir pressure. At times we have found that the sand face has been badly plugged in an injection well; and we have restored the well to its previous injection capacity by back-flowing it. Thus the flow from the well washes away the plugging material from the sand surface. At other times we have lowered a charge of blasting gelatine and exploded it by means of a time bomb opposite the sand face, using the technique already described. With this method, we have improved the reservoir connexion, so that the intake capacity of the injection well was greater, often about double, that of the injection capacity of the well before shooting. So far as we are aware, we have not been troubled at Eakring by sand face blockages due to sulphate reducing or other bacteria. We would not expect aerobic bacteria to be present, as the injection water is kept under air-free con-

ditions; and, although we have experienced a little microbiological corrosion in the water injection pipelines due to anaerobic bacteria, we have no cause to suspect that these bacteria have in any way affected so far the water intake capacities of the injection wells.

With regard to your question on wax deposition in production lines, I do not think that it matters very much whether it is summer or winter from the point of view of its removal. The production pipelines are kept free of wax by pumping a steel plunger with end leathers, known as a "go-devil," along with the fluid production to the stock tanks, at regular intervals. It will be seen that by this method the wax is pushed into the crude oil production, and variations in the quantity of wax deposited are of little consequence, providing the "go-devilling" procedure is carried out sufficiently frequently.

There is, however, another matter which is considerably affected by weather conditions; and that is the pumping of oil emulsions through pipelines, particularly the main pipeline from Kelham Hills to Eakring. At Kelham Hills there is no emulsion treating plant, and only the free water is removed from the total fluid production. During the winter months emulsions form readily, and less free water is knocked-out at Kelham, resulting in more emulsion being pumped to Eakring. Thus the viscosity of the fluid pumped increases enormously, with a corresponding rise in pumping pressures; and much difficulty is then experienced in pumping the oil and emulsion to Eakring. In consequence we have to be very particular during the winter to guard against all conditions which may give rise to the formation of emulsions.

Dr P. E. Kent: A point arising from the figures presented is the correspondence between the increase in production and the rate of water injection per unit volume of sand. This suggests that in the large field of Duke's Wood it might be possible to obtain greatly improved results by doubling or trebling the injection rate. It would be interesting to hear Mr Adcock's comments on this suggestion.

Mr Adcock: The point made by Dr Kent with reference to the correspondence between the increase in oil production and the rate of water injection into the oilfields is an interesting one. At Duke's Wood the volume of oil-bearing rock which is being flooded is about three times the volume of rock at Eakring. Towards the end of 1953 the rate of water injection into Duke's Wood was over three times the rate of water injection into Eakring; but the cumulative quantity of water injected into Duke's Wood is so far rather less than double the quantity of water injected into Eakring, due, of course, to the later start of the Duke's Wood flood.

The gain in oil production per million gallons injected water is, however, very different for the three fields. Over the year 1953, the gain at Duke's Wood was 170 tons, at Eakring 327 tons, and at Kelham Hills 857 tons. The outstanding result at Kelham Hills is attributed to peripheral thinning of the reservoir rock, so that the whole of the injection water is forced into the oilfield area. In addition, it will be seen from the underground contour map that there are only six production wells in the north-west sector of the field in the area above oil–water level. Most of these wells have responded outstandingly to the water flood; and this is attributed to the recovery of oil which would have been obtained by primary methods if additional infilling wells had been drilled in this area.

I agree with Dr Kent on the desirability of injecting the maximum quantity of water into Duke's Wood; and with this end in view we are steadily putting more wells to water injection. There is, however, one point which has to be borne in mind. At Duke's Wood, particularly on the western flank, there is exceptionally free reservoir connexion to crestal wells. There is thus a rapid response to water injection, and in quite a number of instances the production from oil wells has gone almost entirely to water. The remedy is to plug off a large proportion of the reservoir rock. After the wells have been plugged back most of the water is shut off; and in due course the wells become once more good oil producers. Manifestly, these workover operations must keep step with increases in water injection to keep pace with the progress of the flood.

A. Beeby-Thompson: Two important factors, rarely found in most oilfields, facilitated secondary measures of recovery in the Nottinghamshire fields. One was the meticulous care taken in recording well data and in completing the wells to ensure maximum results, the other was the development of each field as a unit without the necessity of considering other interests. Under the direction of the Chairman, Mr Southwell, with the assistance of highly talented experts using every known method, it became possible to embark with confidence on secondary recovery methods. As an old and consistent supporter of secondary methods I have always favoured a water drive when conditions admitted, as that constituted the nearest approach to nature's method of concentration; and I have always favoured edge water introduction in preference to crestal or pattern methods.

I would like to ask the authors whether they have found or anticipate a clogging of the sand pores with paraffin with the diminution of gas and lowering of pressure, and whether emulsions are showing signs of becoming more or less refractory with an increase of water contamination. When initially developed under emergency conditions operating expense was subordinated to expediency, and present operations are doubtless guided by similar circumstances, but it is hoped that one day figures will be made available to demonstrate the economics of the whole project. Meantime, all petroleum technologists will welcome the detailed description of the various methods developed by experimentation in second recovery methods in the hands of a body of talented and keen scientists and engineers.

C. A. P. Southwell: We are grateful for the very interesting paper presented by Mr Adcock and Mr Dickie. The functions of a production engineer and a petroleum engineer are to adopt means towards maximum recovery of oil for the minimum of cost, and this involves much scientific work where secondary recovery is concerned; theirs is an uphill task, because they have got to persuade management to approve expenditure, often on a large scale, when the results are unforeseeable; they must have sufficient confidence in their scientific application in order to justify the expenditure.

Mr Adcock has said that with the water secondary recovery scheme only 40 per cent of the oil, *i.e.* expressed as a percentage of oil contained in unit volume of rock, will be recovered. It appears that it will not be long before the recovery of the other 60 per cent will become an active problem. It might be a very interesting subject for discussion and for speculation on the various methods which may be suitable.

A vote of thanks was accorded with acclamation.

THE INSTITUTE OF PETROLEUM

AN Ordinary General Meeting of the Institute of Petroleum was held at 26 Portland Place, London, W.1, on 10 March 1954, the Chair being taken by the president, Mr H. S. Gibson, C.B.E.

The Editor read the minutes of the previous meeting, which were confirmed and signed as a correct record. He then made various announcements.

The President, introducing the author of the paper to be presented, said: Ladies and gentlemen, it gives me very great pleasure indeed to introduce Dr A. Cameron, who is presenting a paper entitled "Surface Failure in Gears." Dr Cameron took a London B.Sc. and a Ph.D. in chemistry at the Imperial College of Science and Technology. He then gained the Salter's Fellowship in Industrial Chemistry in the department of Colloid Science at Cambridge, and worked on surface films. He joined the Admiralty for work on magnetic mines and then passed on to lubrication problems, and this led him later to the formation of the Joint Advisory Service on lubrication. He joined the Admiralty Gunnery Establishment, working chiefly on gun mountings and their lubrication. After the second world war he looked after research in Germany on gearing and lubrication, and this included the theoretical and experimental on computational work. For two years he did research in the engineering laboratory in Cambridge, and in 1948 joined Pametrada as head of the gearing and bearing section. This involved small scale and theoretical work, as well as full scale testing in marine gearings. Some of this work has been described in a Pametrada symposium, held at the Institute of Mechanical Engineers last March. After leaving Pametrada, he has started consulting work in lubrication.

The following paper was then presented.

SURFACE FAILURE IN GEARS*

By A. CAMERON

INTRODUCTION

THIS paper is a sequel to the one read in the symposium on lubrication held at the Institute in 1952. It attempts to consider the actual failure of gears instead of their successful lubrication. Two aspects of failure will be studied: scuffing and pitting.

LUBRICATION OF GEARS

The lubrication of gears poses two separate problems. The first one is: how does the oil film form between gears, and what is the mechanism that allows the surfaces to be separated by oil, considering the huge pressures existing between them? The second is: having once got an oil film, what causes it to fail?

The elementary theory shows that a film is built up as the speed increases, and that increasing it further raises the temperature of the oil film so that the latter breaks down again.

These two parts, the formation and breakdown, have been illustrated very well by some experiments published by Watson.[1] He showed that as the speed increases the breakdown load rises to a maximum and then drops again. These two parts will be considered separately in the following sections.

(i) *Formation of the Oil Film*

In a recent paper[2] the theoretical background of gear lubrication was discussed and it was shown that the hydrodynamic theory could act as a guide to the phenomena which are known to occur. It was not very satisfactory for the actual quantitative analysis.

The basic formula for the load carried by gears is

$$W = 2{\cdot}45\eta\,(V_1 + V_2)\,R/h_0$$

where W = load carried per unit width;
η = viscosity;
$(V_1 + V_2)$ = velocity of disks 1 and 2;
R = mean radius given by $1/R = 1/R_2 + 1/R_1$;
h_0 = minimum film thickness.

This formula assumes constant viscosity and undeformed circular disks.

It is clear that the very high pressures produced by the oil between rotating gear teeth (or disks) will deform the metal surfaces. A theoretical treatment[3] of this problem suggests that the actual oil pressure approximates to the Hertzian pressure. This Hertzian pressure is the one predicted by the standard elastic theory of two loaded cylinders in contact. This result is not at all surprising; in fact, experiments on pitting have already led to this conclusion.

One may then consider the oil film pressure curve to be, for all practical purposes, the same as that obtained from the classical elastic theory assuming that the two cylinders are in direct contact, without any intermediate oil film.

A few calculations show the mean pressure is in the region of 2000 to 4000 atmospheres. At these pressures the oil must have very different properties from the ones measured at standard atmospheric pressure.

First, there is the adiabatic heating to be considered—the figure for oil is about 1° C for every 100 atmospheres. There is a rise and fall of 20° to 40° C for the passage of the oil past the point of contact. Secondly, there is the effect of pressure on viscosity.

* This paper is based on one read[16] before the Société d'Études de l'Industrie de l'Engrenage in Paris on 23 March 1953. MS received at the IP 27 May 1953.

If undeformed disks are postulated, this will explain the fact that load plays only a secondary role in the lubrication of disks. That is the disks become oil-borne at a given speed, mainly independent of load. This simple theory [2] must be modified in the light of the finding that the disks take on the Hertzian pressure curve as a result of deformation.

One of the chief difficulties of working with gears is that the zone where the oil pressure is formed is so small that no observations can conveniently be made in it. For a long time the author has thought that the electrical resistance is the most logical way of investigating the oil film.

A number of experiments were made and published [4] showing the effect of applied voltage on resistance. If more extended results, recently obtained, are plotted, not in the form shown in that paper, but as curves of resistance against current, a very interesting relationship follows (Fig 1) for currents above about 1 amp:

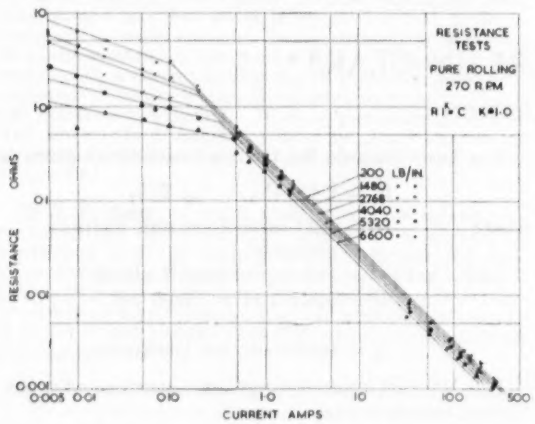

Fig 1

$$C = RI^k$$

where C = constant;
R = resistance;
I = current;
k = constant.

If k is 1, then the constant C is the breakdown voltage of the insulating oil film. It means that whatever the current the potential across the oil film is constant.

Briefly, the mechanism is that the voltage causes a discharge to pass through the oil. This discharge will ensure that any amount of current can pass, as the oil and oil vapour are heavily ionized. This heavy ionization occurs only for the higher currents. At lower values of current the oil behaves more or less as an ohmic resistance. This is shown by the current–resistance curve being comparatively flat, *i.e.* with $k \to 0$. If the oil film was a pure ohmic resistance, k would be zero and the resistance would be a constant, for given conditions.

In Fig 2 the values of C have been plotted against load for various speeds. The load curves in this figure are extrapolated back to zero load, and the values of C so found are plotted against the speed in Fig 3.

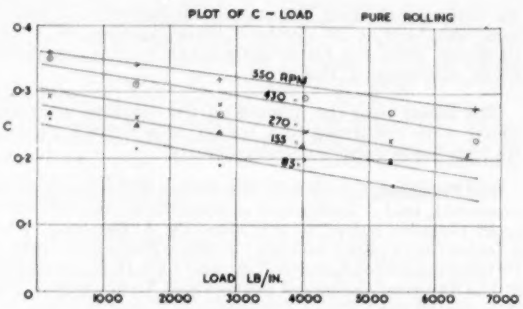

Fig 2

The experimental results show that the constant k is not exactly unity at higher currents, but the graph shows that it is not very far away from 1.

The disk machine used was one designed and built at Pametrada. It consists of disks 4·5 inches in diameter, with a contact width of 0·25 inches. One disk was insulated from the shaft and slip rings enabled current to be passed through the oil film. A separate pair of slip rings, connected to the periphery of the disks, was used to measure the potential drop across the oil film. The material used for the disks was 3·5 per cent normalized nickel steel, as used for pinions of marine gears, of 40 to 45 tons/sq. in., running against 0·3 per cent carbon steel (about 30 tons/sq. in.). The oil was standard turbine oil of 88 cs viscosity at 100° F. The electrical resistance measurements were done under conditions of pure rolling, that is, each disk rotated at the same speed.

The resistance at zero speed was measured and found to be constant with load. It amounted to a few milliohms and was subtracted from the measured values.

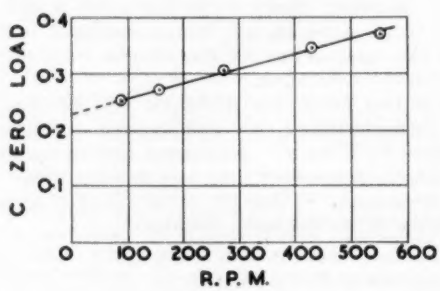

Fig 3

If the value of C is computed from Figs 2 and 3 it is seen that it obeys the law

$$C = 0{\cdot}23 + 5{\cdot}6 \times 10^{-4}V - 1{\cdot}5 \times 10^{-5}W$$

where V = rolling velocity $(V_1 + V_2)$ inch/sec;
W = load, pounds per inch face width

within the range of variables investigated, and for this system. If the breakdown voltage is assumed to be a measure of the film thickness, as McEacheron's results [5] would lead one to suppose, we see there is a film formed at very low speeds. There is a finite value of C at the lowest speed investigated. Lubrication theory requires film thickness to vary directly with speed at any given load. This experimental work has demonstrated the failure of the classical theory, as a complete oil film is formed at very low speeds.

A similar result may be found in some experiments by Beeck, Givens, and Smith.[6] They used a four-ball machine running at very low speeds. The co-efficient of friction dropped at a speed of a few cm/sec, giving fluid friction. The theory of the four-ball machine published by Howlett [7] showed this was far too slow a speed to give full fluid lubrication.

These two observations are probably examples of the same phenomenon.

It is possible to suggest that an explanation may exist in the concept first postulated by Clerk Maxwell.[8] He pointed out that if fluids are deformed very fast they behave like solids. The reason is that the applied strain requires a finite time for the fluid to move, and so allow it to be relaxed. If the time allowed is shorter than the " relaxation time " of the fluid, the fluid behaves as a solid. The relaxation time τ is defined as the time for the internal stress to fall to $1/e$ of its original value. It is given by the relation $\tau = \eta_i/G$, where G is the shear modulus of the liquid. For oils this is about 10^7 dynes/sq. cm.,[9] and η_i is the viscosity as before.

This means the relaxation time is 10^{-7} sec for each poise. If the pressure–viscosity effect comes into play, the viscosity will be much higher and the relaxation time correspondingly longer. The surfaces of the disks are always rough, and if the time taken by one roughness to move past a roughness on the opposing surface is of the same order as the relaxation time, then the liquid will not flow. It will behave as a solid, and the surfaces will be coated with a layer of rigid oil.

Heidebroek [10] has for a long time put forward a postulate of a rigid film of oil on the surface of metals. He, however, says it is due to surface orientation. In the complete absence of active polar groups, it is very hard to see how this orientated layer could be formed.

It was thought the surface tension might contribute to the oil film formation. This would come about in the following way. When the disks run together, the oil film breaks behind (or downstream) of the contact point. There will be a pressure difference across the meniscus, as explained in textbooks, of $(2\gamma/h)$, where γ is the surface tension and h is the film thickness. This will alter the boundary conditions which are usual in lubrication. The oil film, instead of ending at the point $x = a$, where $p = dp/dx = 0$, will break at the same point where $dp/dx = 0$ and $p = 2\gamma/h$, there being a discontinuity in pressure equal to $2\gamma/h$ at this point, $x = a$. The extra load carried will be obtained from the integral $\int_{-\infty}^{a} p\,dx$, where $p = 2\gamma/h$. This integral is simply carried out by the usual substitution, putting $h_0/h = \cos^2\phi$, where $h_0 =$ minimum film thickness. The integral is carried out between the limits $\phi = -\pi/2$ and $\phi = \alpha$. α corresponds to the point $x = a$, and equals 0·4435 (see references in the author's previous paper).

The additional load, W, carried per unit axial length of the disks is found to be

$$W = \left(\frac{\pi}{2} + \alpha\right) 2\gamma \sqrt{\frac{2R}{h_0}} = 4{\cdot}0286\gamma\sqrt{\frac{2R}{h_0}}$$

where R is the mean radius.

In the disk machine considered here, $R = 1{\cdot}125$ inches and $h_0 = 5 \times 10^{-6}$ inches (say). If $\gamma = 30$ dynes/cm, which is $1{\cdot}7 \times 10^{-4}$ lb/inch, then $W =$ 0·45 lb/inch.

The surface tension, therefore, on this analysis, does not allow the support of any appreciable load, unless the value of γ is the interfacial tension, equal to some hundreds of dynes/cm.

If the formation of this oil film at low speeds can be explained, the lubrication of gears would be better understood.

(ii) *Breakdown and Scuffing*

What causes the oil film to break down? A certain amount of work [11, 12] has shown that in gears the limiting factor is the amount of energy dissipated at the surface.

If an attempt is made to analyse these results, difficulties occur almost at once. First, the temperature *rise*, calculated by the method given by Blok,[13] is very small. For disks, it is of the order of 40° to 80° C, and in gears the same temperature rise is found, though the problem is rather more complex owing to the difficulties of the coefficient of friction.[14]

It does seem, however, that scuffing is correlated better by the temperature flash than by any other method. If this is so, what is the detailed mechanism causing the gears to scuff? There are various possibilities, but all require proof.

In the first place, it may be bound up with the interesting fact, not hitherto applied to gears, that all steels, except those containing a large percentage of alloying metals, start to soften at about 250° C. If it is assumed that the local temperature rise at the actual point of contact just prior to scuffing is at this value, there is a possible explanation. If the gear surface gets any hotter, the area of contact will increase as the surface starts to soften. This will cause the friction to rise, which increases the temperature, and the whole system fails. This, however, does not account for the effect of E.P. oils or silver plating,[15] which do not materially lower the coefficient of friction, but raise the scuffing load two or three times.

Another hypothesis is that the temperature is required to be high enough to destroy the oxide film

which always exists on the metal surface. This is an attractive idea, as it means that systems lubricated by extreme pressure oils, which form chloride or sulphide films, will fail when the surface temperatures are high enough to disrupt the chlorides or sulphides so formed. What does not seem so satisfactory is that a temperature very much in excess of 200° or 300° C would seem to be required to disrupt these iron compounds, which chemically are very stable.

There is also the theory that the temperature causes an oriented layer of oil, adsorbed on to the surface by chemical forces, to be ruptured. Against this can be raised the fact that the scuffing load of a completely neutral mineral oil is not very much increased if 1 per cent or so of a fatty acid, such as stearic or oleic, is added to it. The addition of this acid, which is

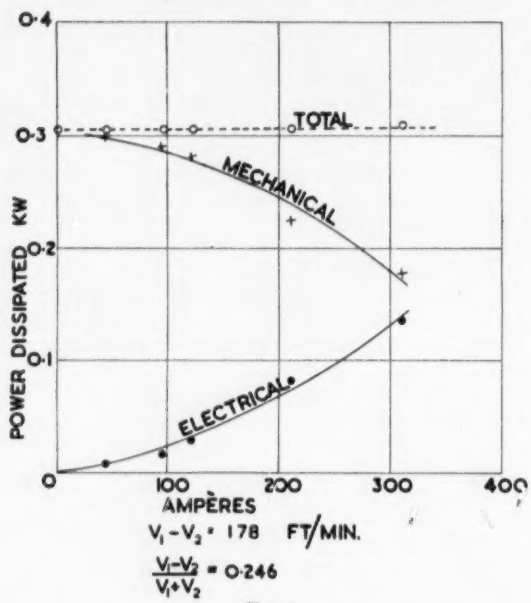

FIG 4

known to form a strongly oriented film on steel, makes very little difference to its load-carrying capacity.

The theory I suggest, though with no experimental backing, is that scuffing is a type of " cold " pressure welding. This is brought about in normal welding practice by pressing two pieces of metal together, without any external means of heating, so that a considerable amount of plastic deformation occurs. This breaks, by mechanical means, any oxide film on the surface, exposing the pure metal below. The two metals then seize, or weld together, by molecular attraction.

In gears, the sequence of events will be on this postulate approximately as follows: The local temperature reaches 250° C, due to the flash temperature and possibly the adiabatic heating. This causes the surface to soften, and the consequent yielding will rupture the oxide film present on it. This temperature is high enough to ensure that any layer of oil or fatty acid is in an unoriented and easily removable condition. The two metal surfaces will then weld together as a result of the pressure exerted between them. The effects of E.P. oils and of silver plating fall directly into place. The chloride or sulphide layer formed by these oils is more plastic than the oxide film, hence it will resist rupture (consequent on the yielding of the metal) much better than the rather brittle oxide film. The same can also be argued for the silver or copper films on steel. The existence of a layer of a foreign metal will prevent the two steel surfaces welding together. The requirement is for a metal of a different molecular structure to remain ductile at the very high pressures in the contact zone so it can follow the flow of the steel surfaces and keep them from welding together. Methods of proving this hypothesis are not very easy to devise.

First, a precise formula is needed for calculating the temperature of the metal surfaces. The pioneering solution of Blok[13] is only approximate, due to the mathematical difficulties involved.

An experimental method has been attempted at Pametrada Research Station. It has been seen that there is a resistance at the contact point due to the oil film, hence if a very heavy current is passed an amount of energy of the same order as the energy produced by the friction of the two disks, just prior to scuffing, can be dissipated. The results from these experiments (Fig 4) show that the total amount of energy dissipated at the contact is constant, whether it is made up of electrical or mechanical components. This indicates that heat, and hence the surface temperature, is the deciding factor in these scuffing experiments.

In conclusion, it may be objected that in all this work hardly any mention of the oil has been made. The formation of the oil film is dependent on viscosity and also the Maxwell relaxation time is proportional to it. The breakdown and final scuffing is also dependent on viscosity (shown experimentally both by Mansion and Cattaneo) to keep a sufficient oil film between the metal surfaces to ensure that the coefficient of friction is low. The flash temperature is proportional to the friction, hence the lower it is the further the system is from scuffing. Therefore it can be seen that the hydrodynamics of the oil film are important.

PITTING

At the moment pitting probably occurs on the majority of marine gears. It is usually not regarded as being very serious, and only very rarely does it get so bad that gears have to be changed because of it.

A great deal of work has been done on the experimental side of pitting, usually using disks, which are kinematically similar to gears. Some of the findings of the work done at Pametrada on pitting are detailed,[14] and one micrograph will summarize almost all the results (Fig 5).

First, less than 5 per cent of the cracks seen were below the surface, hence it is most likely that they start from the surface. It was considered that the few subsurface cracks were either due to the method of sectioning to or subsurface inclusions in the steel. The shape of the crack makes it improbable that it has started below the surface and worked upwards.

Secondly, the crack is oriented by the flow of the metal. It is seen to be parallel to the grain distortion, which is caused by the traction of the contact. This means that the cracks are always oriented away from the pitch line in a driven gear, and towards it when the gear is driving.

Cracks are formed in both the addendum and dedendum, but only those in the dedendum extend to form pits. This can be explained by the fact that the point of contact moves from the crack mouth to the tail of the crack when it is in the dedendum. This occurs both in driving and driven gears, as can easily be seen from the kinematics of involute teeth. When this happens, oil is trapped in the crack by the mouth closing, and is progressively compressed as the contact point moves. The crack is extended in this manner. Way [16] has found that if a small hole is drilled from the surface to the tail of the crack, the compressed oil can escape and no pit is formed. This is easily explained from these results. Cracks have been photographed in all stages of development, from very small surface hair cracks, well under $\frac{1}{1000}$ inch long, right up to the stage shown in the photograph, and beyond, when a piece of metal has fallen out to form a pit. In these cases, the crack extends beyond the pit. It is usual for the crack to extend to a depth of two or three times the depth of the pit.

The cause of the start of the crack is uncertain. Niemann [17] has noticed small pin holes or pores forming in the surface of the steel during rolling tests. These have also been noticed at Pametrada, and microphotographs taken of them. These micropits are about 0·0002 inch deep. There is no trace of any grain distortion associated with them. It may well be that these form points of weakness from which the cracks start.

It has been found at Pametrada that a pit can actually be the start of a crack which extends right through the tooth and leads to tooth breakage. A crack 3 mm long starting from a pit was found in one micrograph.

The fact that pitting is correlated with the Hertzian stress set up by the load is confirmation of the theoretical finding, mentioned in the section on scuffing, that the pressure curve of the lubricating oil approximates to the Hertzian curve.

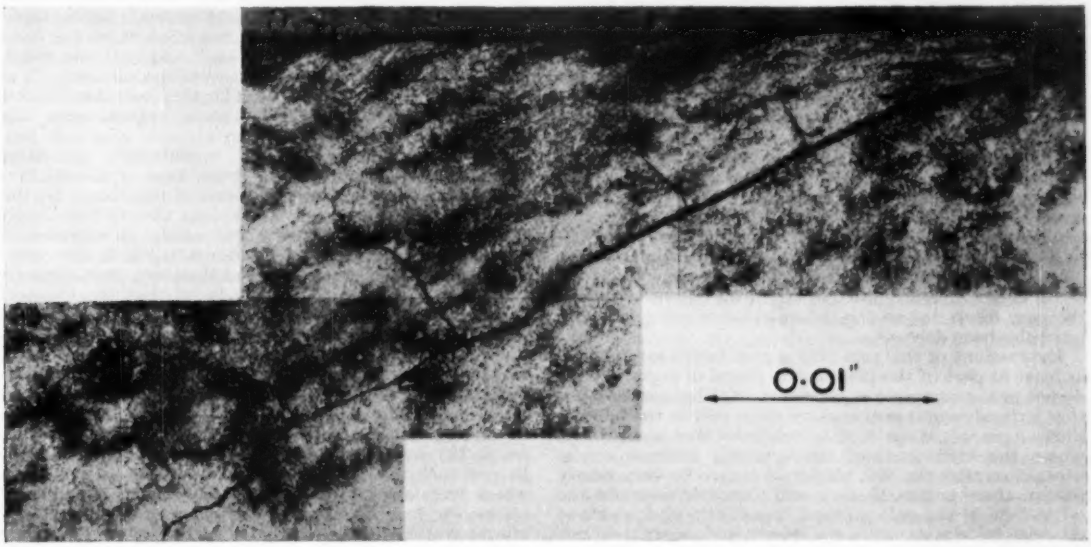

FIG 5

MICROPHOTOGRAPH SHOWING CRACKS DUE TO PITTING

ACKNOWLEDGMENT

The experimental work reported here was carried out at Pametrada Research Station, and the author is grateful for permission to publish it.

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DISCUSSION

T. B. Lane: I agree with Dr Cameron that there is a bit of a mystery about the formation of an oil film in gears. In his present paper Dr Cameron remarks that as opposed to an earlier one, read at the Gear Symposium in 1952, he proposes to discuss gear failure rather than the lubrication of gears. However, he has run through various ideas about the lubrication of gears, and so I propose to take a leaf out of his book and do likewise.

For a long time, as far back as 1916, the Reynolds equations for viscous flow have been applied to the system of meshing gears; and expressions, such as that quoted on p. 191 of Dr Cameron's paper relating the load-carrying capacity of the system to the gear variables, have been obtained. More involved expressions, which take into account the increase of the viscosity of lubricants under pressure and the beneficial effects arising in the gear mesh due to the deformation of the gear teeth, have also been derived.

Expressions of this sort give a qualitative explanation at least in part of the phenomena found in gears. They do not give a complete explanation, but there is no doubt that hydrodynamic action plays some part in the lubrication of gears. Even if it is imagined that a condition where the high spots of the opposing surfaces are in contact so that the film thickness is zero or very nearly zero at these points, there is still plenty of room for the oil to flow in the valley round these little peaks, and so oil will be drawn into the mesh and hydrodynamic pressure will be generated. These little peaks are important, and I shall refer to them again later.

Pressures generated in this manner would, however, as calculated in the conventional manner appear to be small compared with the mean pressures due to the applied load. As Dr Cameron suggests, however, there may be other mechanisms at work, giving rise to these pressures, and their existence may be demonstrated. The experiments of Barwell and Milne,* for instance, show that considerable hydrodynamic pressures are generated in sliding contacts under conditions where classical theory would indicate no pressure formation at all.

Other evidence, supporting the view that hydrodynamic action is present, is of indirect nature. I refer to experiments with disks running in contact, such as that described by Dr Cameron, and those using balls, such as in the two-ball and four-ball machine. Here it may be shown that the coefficient of friction falls as the speed increases. This is perhaps at variance with one of Dr Cameron's remarks, *i.e.* the friction which he measured in gears remained constant with speed. Under full hydrodynamic conditions, the coefficient of friction increases as the speed increases. The explanation of this fall is that as the speed increases, the load carried by hydrodynamic action increases too, thus reducing the magnitude of the load carried by another mechanism of lubrication which is also playing a part in the sliding contact. It would seem as if this latter kind of lubrication is capable of carrying very high load, since there can be very big discrepancies between theory and practice, as Dr Cameron points out, even after allowing for the beneficial effects that I mentioned earlier. Under these conditions there is the type of lubrication which has been designated "thin film lubrication," and it is one about which there has been a great deal of speculation. It is therefore very welcome to hear Dr Cameron describe his experiments which probe, to some extent, into this region.

Dr Cameron has described experiments in which measurements of the electrical resistance of the oil film have been used to gain some idea of the nature of the film. Fig 2 in his paper shows that the oil film thickness increases with the speed of the disks, as expected in hydrodynamic theory, but as shown in Fig 3, the curve of film thickness against speed does not pass through the origin. From this it is deduced that the classical theory fails. Complete details of the experiment are not given, but it seems that even at low speeds, the formation of a thick hydrodynamic film in the classical sense, would not be out of the question. Making use of the data given on page 193 for film thickness, at a disk speed of 85 r.p.m. and an oil viscosity of 0·75 poises, the load capable of being carried as deduced from the equation on p. 191 is, if my calculations are correct, about 500 lb per inch. This is greater than some of the loads which were employed, and in calculating this value, no allowance has been made for the various beneficial effects, which are known to be important in the formation of the oil film.

This being so, it is not surprising that the film thickness does, in fact, increase with speed. The reason why it does not, in these experiments, increase in the expected way, may be because as the speed increases, the temperature of the oil film rises in the manner outlined by Dr Cameron in his opening paragraph, thereby decreasing the viscosity of the oil, and the film thicknesses are therefore lower than might be expected. I realize that in these experiments, since the disks were rolling, frictional heat will be lower, but could not the electrical energy which was supplied in these experiments have some effect?

Oil film thicknesses have been deduced from the slope of the right-hand part of the curve in Fig 1, since these parts of the curve indicate that the insulation of the oil film has broken down, and that a measure of the breakdown voltage gives an indication of oil film thickness. However, the left-hand part of these curves are far from flat. It would seem that, even in this region, the behaviour of the oil film is far from ohmic and that some breakdown has already occurred. For example, the curve for 200 lb per inch load varies from about 8 to 3 ohms in this region. Incidentally, resistances of this magnitude would indicate extremely thin films of almost molecular dimensions, if based on the values normally quoted for conductivities of oil. Can it be that under the experimental conditions corresponding to the later stages of the curve, some metallic contact is taking place?

Dr Cameron refers to the paper given by Beeck, Givens,

* Barwell, F. T. and Milne, A. A. *J. Inst. Petrol.*, 1952, **38**, 624.

and Smith, but I wonder if the mechanism of film formation in their case was actually the same as in the present instance. As I recall, the experiment was with a four-ball machine and carried out using an oil containing a fatty acid, and the authors postulated that it was the polar molecules being dragged into contact which enabled the friction to fall. If so, these were special conditions not applicable to straight mineral oils. The data given by them showed that at higher speeds than the one they used for demonstrating the effect of the oil containing fatty acid, they obtained evidence about film formation with an inert mineral oil. Dr Cameron's suggestion that "relaxation time" plays a large part in the formation of the oil film is a good one. Can Dr Cameron tell us whether the shearing forces between the opposing roughnesses are really of short duration in the experiments with rolling disks, as illustrated in Fig 1? It appears that the surfaces in contact were approximately parallel, moving in the same direction at the same speed. However, relaxation phenomena will also be important in the squeezing action which will be imposed on the oil, and this may account for the oil formation in rolling motion.

In regard to scuffing; it is true that the application of Blok's flash temperature hypothesis to gear lubrication, has provided a satisfactory explanation of the observed phenomena in gears. It is difficult to see, however, what the real meaning of this flash temperature is. Blok has always emphasized that the temperature for failure is a function, not of the lubricant alone, but a combination of the lubricant and the sliding elements. It is not surprising, therefore, that differences in the magnitude of the temperature flash are found when different systems are considered. Maybe surface roughness has something to do with it. For example, Kelly * has shown that scuffing loads for gears falls as the roughness increases—at least, within the range of his experiment—where the roughness varied from 7 to 27 micro-inches. Blok's flash temperatures are calculated ones, based on the assumption that the frictional heat is distributed in a continuous though not uniform manner over the surface. It will be recalled that the distribution of pressure and heat in gear contacts is semi-elliptical in form, following the application of the Hertz theory. May it be that within the contact the load is not carried uniformly on the surface but concentrated on the high spots which are in contact, and thus instead of having a uniform distribution of the sort given by the Hertz theory, there is one with many peaks superimposed on the general background during this semi-elliptical distribution. The magnitude of the calculated temperatures is not high, and they can vary from one machine to another, *e.g.* with disks, temperatures at scoring may be, as Dr Cameron has found, as low as 50° C. When using an oil of the same kind which gave this value in a machine using two balls running together, the flash temperature is much higher, being in the region of 150° C. Where flash temperatures have been measured, as in the experiments of Bowden and Ridler,† they are much higher. It seems, then, that the distribution of heat in a sliding contact is such that there exists a series of hot spots, and that the number of hot spots will vary according to the roughness of the surface. It is possibly the temperature of the hot spots themselves which determine whether or not seizure will occur.

With a rough surface, where a number of points of real contact may be expected to be lower than with a smooth one, the necessary seizure temperature at these points will be reached at a lower total load than when the number of points carrying the load is greater. Thus, the flash temperature will be lower for a system whose sliding surfaces are rougher. For a given system, therefore, the flash temperature is an index of the temperature of the hot spots.

The mechanism by which the opposing surfaces actually weld together is rather speculative, and as Dr Cameron points out, various possibilities have been described. There is little doubt, however, that the important factor is temperature, but it seems unnecessary to postulate a low temperature for the parts about to weld. The relatively low flash temperatures, as calculated, represent the mean temperature within a contact, and possibly have some meaning as far as the lubricant film itself is concerned. When the temperature is high enough, the support, which the lubricant can give, falls, so that additional load is thrown on to the high points. Hence the local temperature rises to such an extent that seizure takes place. The times during which a high point remains in contact is very short, and therefore it must be expected that scuffing takes place almost instantaneously. This is generally recognized. There is no gradual approach to failure.

It is not clear, however, what particular quality of the lubricant is important in keeping the surfaces apart. In gears various workers have shown that load-carrying capacity is dependent on the viscosity of the lubricant. The viscosity considered by various workers, however, has been the bulk oil viscosity or even the viscosity grade of the oil. It is very difficult to predict the actual viscosity of the oil in contact, where combinations of high temperature, pressure, and rates of shear occur, but there seems to be no doubt that the size and shape of the molecule is an important factor. It is clear that more research into the elucidation of the nature of this film is required.

Dr Cameron: The calculations done by Mr Lane show that a part of the load can be carried by normal hydrodynamic means, but this is only 10 per cent or so of the whole, even if the smallest possible film thickness is postulated. This is, of course, the trouble one meets, as soon as any quantitative calculations are done on the problem. It is in fact the whole kernel of the difficulty.

The question whether the metal is elastic or plastic at the contact point needs a paper in itself. A certain amount can, however, be said; first, the area of Hertzian contact is smaller than the plastic area, at any rate with mild steel disks. Hence the concept, which holds in the case of flat plates, that the load is carried only on a few isolated high spots, is not really applicable here. This means that the whole area is in contact. High surface temperatures, prior to scuffing, do not apparently occur. The highest I have measured, using bronze and steel disks as thermo-elements, are all under 200° C. This is reinforced by the fact that microsections, taken from disks run just below scuffing point, do not show any recrystallization when viewed at the highest possible magnification. This shows that the temperature cannot have reached the very high values usually demanded by the concept of "high," and consequent "hot" spots.

The thesis of this paper is that thin film lubrication is something *sui generis*, neither boundary nor classical fluid film lubrication, though, of course, it runs into boundary at very slow speeds, and (possibly) into full fluid at high speeds. It has laws of its own, and the method of forming and breaking down its oil film is still unknown.

A. W. Crook: I would like to ask Dr Cameron whether it is essential to invoke the fact that carbon steels start to soften at about 250° C in order to make the postulate of plastic flow plausible. I think that at the higher loads plastic flow occurs at room temperature.

At the higher loads I do not think it is just a question

* Kelly, B. W. *Trans. Soc. automot. Engrs*, 1953, **61**, 175.

† Bowden, F. P., and Ridler, K. E. W. *Proc. roy. Soc.*, 1936, **A154**, 640.

of plastic flow of the asperities; but what I am suggesting is that macroscopic flow of the disks occurs. According to Michell,* ball races are designed to run at loads which produce such a flow, so there is nothing improbable about disks running in similar circumstances.

Dr A. Cameron: Mr Crook's comments are interesting, and the problem of elasto-plastic flow is important. The fact that carbon steel has its peak strength at 250° C is the basis of this hypothesis. Up to this temperature any rise in frictional energy will not cause an increase of area of contact until the peak is reached. Beyond that, any further temperature rise causes a softening of the steel, with increase of area followed by another increase of the temperature, thus leading to breakdown.

The problem of how much plastic distortion there is in a normally pitted gear is clearly very complex. Hertz's elastic theory fits the experimental results very well, yet micrographs of disks under very heavy loads, as in Fig 5, show a lot of grain distortion. Other micrographs show very little. It is clear there is still much work to be done on this point.

A. W. Crook wrote: The following calculations and experiment show that macroscopic plastic flow may occur under the conditions used by Dr Cameron.

For mild steel Mohr's criterion of plastic flow is appropriate,† *i.e.* the material flows when the maximum shear stress is $0{\cdot}5Y$, where Y is the yield stress. In conjunction with Hertz's equations for disks, this criterion gives the relationship

$$P^1 = \frac{100\,Y^2}{6{\cdot}45\,E}\left[\frac{R_1 R_2}{R_1 + R_2}\right]$$

where P^1 is the load per unit length at which plastic flow commences, Y is the yield stress, E the Young's modulus, and the term within the square brackets is the relative radius of curvature. (It is assumed that Poisson's ratio is 0·3.)

Taking $Y = 20$ tons inch^{-2} for a steel of 30 tons inch^{-2} U.T.S., $E = 3 \times 10^7$ lb inch^{-2} and $R_1 = R_2 = 2{\cdot}25$ inches gives $P^1 = 1170$ lb inch^{-1}. I assume, since Dr Cameron gives a resistance–current curve at a load of 6600 lb inch^{-1}, that his 0·3 per cent C steel disk ran at this load without scuffing. It can be seen that this load is about six times the load for the onset of plastic flow at room temperature.

In order to verify the existence of plastic flow under these conditions, I have pressed a lapped mild steel disk of 1·35 inches radius against a lapped 3·5 per cent nickel steel flat. This arrangement gives a relative radius of curvature of 1·35 inches, which is greater than that of Dr Cameron's disks (1·125 inches). The disk had a V.P.N. of 143 kg mm^{-2}, which implies a U.T.S. of at least 30 tons inch^{-2}.‡ The nickel steel had a V.P.N. of 280 kg mm^{-2}. Care was taken to make the loading uniform, and in the figure profilometer traces taken at the ends and centre of the 9 mm long impression are given. The load was 2500 lb, which is equivalent to a load of 7000 lb inch^{-1}. It is evident that macroscopic plastic flow has taken place.

Disks running at such loads need not necessarily undergo a continuous process of plastic deformation, for up to a certain load the work-hardening of the material by the initial plastic strains may restore elastic conditions. But even so, the plastic flow has occurred, and yet the disks have not scuffed.

A greater amount of plastic flow will occur, of course, if the material becomes soft at the temperatures in the region of contact. It is, however, important to note in this connexion that whilst carbon steels begin to soften at about 250° C, it is also at this temperature that they may be at their strongest.§

Dr F. T. Barwell: In reference to Mr Crook's remarks, whilst I am not prepared to comment on gears, it would appear that plastic flow does occur in rolling bearings. This may be confined to the initial stages of operation. I was a little puzzled by Dr Cameron's reply on this point, because in Fig 5 there does appear to be evidence of plastic flow, and on p. 195 he comments that grain distortion is caused by the traction of the contact.

Referring to p. 193, the suggestion that plastic flow enters into the mechanism of scuffing is very attractive, but it must be remembered that experiments have shown that considerable plastic flow may occur within the bulk of a material without the surface texture being seriously modified. The idea is important, however, because it leads to the conclusion that it is not essential for the surfaces to reach their melting point before scuffing can occur. Referring to p. 193, Dr Cameron has rightly drawn attention to the importance of a mode of lubrication which cannot be precisely defined either as "boundary" or "hydrodynamic." The relaxation idea is attractive, but it may be necessary to take into account local deformation of the surfaces in any analysis.

Regarding the incidence of pitting, there is a danger that workers in the field may become divided into two schools, one supporting the view that pitting failure is always initiated below the surface in the region of maximum shear stress, the other asserting that failure always commences at the surface. It is probable that both views are correct in so far that the location of initial failure may be dependent on particular conditions governing the application. Considering Way's experiments, is it possible that the nature of the lubricant may affect the rate of progress of a crack? For example, one would expect the pressure–viscosity characteristics to be important in this connexion.

Dr A. Cameron: Plastic flow in pitting, as far as I have seen it in mild steel disks and gears, is rather variable. In the case of the crack shown in Fig 5, the disks were very heavily overloaded. In other cases very little plastic flow has been observed.

I am interested in the location of the start of pits. As far as mild steel gears are concerned, the point has been reached where it can be said that less than 5 per cent of the cracks seen were below the surface. I should very much like to see a similar analysis of those cases where sub-surface cracks are postulated. Case-hardened steels are, of course, different, due to the existence of a softer core.

It has been reported several times that a thick oil delays the onset of pitting. This can reasonably be ascribed to the difficulty of thick oils penetrating the crack. This is accentuated by the pressure viscosity effect. Thick oils have a larger pressure viscosity coefficient than thin oils.

J. L. Heaton: In discussing the matter of pitting and cracking leading to pitting, it must be borne in mind that a normal kind of fracture is being dealt with, as Dr Cameron has just indicated. Also it is a well-known fact that the fatigue strength of steel is very roughly half its tensile strength. In other words, the fatigue strength may be a little less than the stress at which it begins to yield. There is, therefore, no need to postulate plastic deformation as the starting point for any sort of

* Michell, A. G. M. "Lubrication." London: Blackie and Son Ltd., 1950.

† Tabor, D. "The Hardness of Metals," p. 29. London: Oxford University Press, 1951.

‡ Smithells, C. J. "Metals Reference Book," p. 511. London: Butterworths, 1949.

§ Sisco, F. T. "The Alloys of Iron and Carbon," p. 434. London: McGraw Hill Publishing Co., 1937.

fatigue cracking, whether it is bulk cracking or the sort of cracking that leads to surface pitting. This applies, of course, whether the point of maximum stress is postulated as being under the surface, as in most theories of indentation, or whether it is assumed that the maximum stress arises due to surface irregularities, and is more nearly at average surface level.

I find this conception of "pseudo hydro-dynamics," and in particular this suggestion of a thick oil film always existing between gears, to be somewhat startling. I wonder, for example, just what the mechanism of eventual lubrication failure is when one starts loading up a pair of gears which normally operate with such an oil film between them. If there is a gear train which is running light or in such a way as to give complete freedom from scuffing, there is this fluid film of definite thickness between the teeth. Then, if the gear train is loaded up

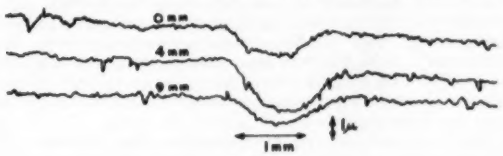


FIG 1

PROFILOMETER TRACES ACROSS THE DEPRESSION IN TRANSVERSE PLANES

so that it nears the point of lubrication, and this is followed by a little bit more additional loading so that it fails, what happens? Does the oil film suddenly disappear, allowing the gears to touch together with a bump, or does it gradually become squeezed out until there is some kind of contact between mating teeth? If the latter case is true, and it surely must be true in simple logic, the condition between gear teeth just before failure is contact between high spots. If the loading up process is interrupted at this point the gears will go on running, and they are not, of course, then separated by continuous fluid film.

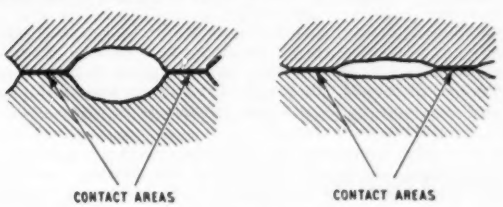


FIG 2

There are two other points I would like to mention. First, the fact that gear teeth can wear before failing, which Dr Cameron mentioned himself; secondly, the fact that their life under high load can be prolonged by avoiding scuffing if certain chemically active materials are used in the oil. Those chemically active materials modify the solid surfaces, and would surely not be effective when dealing with an oil film greater than 0·0001 inch thickness and where there was no contact between high spots.

The point which worries me most of all in connexion with Dr Cameron's proof of his "pseudo-hydro-dynamics" is that it depends to some extent on measurement of electrical conductivity or resistance across an oil film. I have understood for some time that the apparent conductivity of an oil film between moving metal surfaces is a function not of its thickness but of the number of points at which it has been broken through.

Fig 1 represents two lubricated solid surfaces in contact at high spots, and Fig 2 shows two more surfaces in contact. There is the same area of contact in both cases. Therefore the measured electrical resistance between the two contacting surfaces is the same, although the average oil film thickness is very different. It is necessary to be very careful in describing oil film thicknesses in terms of electrical resistance.

I should not like to go on record as suggesting that the oil pockets represented in my sketches are unpressurized. I have a great deal of sympathy with Dr Cameron's suggestion that hydro-dynamics play a vital part in gear lubrication. My argument is concerned simply with his assumption that the minimum film thickness is such that boundary lubrication between mating teeth is precluded.

Dr A. Cameron: It is, of course, commonplace that gears run in and polish. This must mean there has been contact between the roughnesses, leading to their being torn out or otherwise removed, so giving a finer finish. Now in Hertz's elastic theory the pressure at the edges of the contact zone is zero, thus the roughnesses there will not be deformed. They will therefore interfere and touch. It is clear that contact at the high spots will not cause, automatically, the gears to seize and the lubricant to fail. The change from satisfactory lubrication to failure occurs, on the hypothesis put forward in the paper, when the surface temperature reaches such a value that the gear steel has attained its peak strength and starts to soften, at about 250° C.

The value of breakdown voltage of 0·23 volts corresponds to a film thickness of about $0{\cdot}4 \times 10^{-3}$ inches. This will be studied in more detail as opportunity occurs. At the moment the only comparable data are given by Brix.* As a start the simplest method would seem to be to place two microscope cover slips, on a surface plate, with a V-shaped gap between them. If a steel ball is rolled between them the distance between the ball and the plate can be calculated from the thickness of the cover slips and the angle between them. The breakdown voltage can be measured and plotted against the gap. The advantage of this method is that the discharge takes place at a fresh spot and through fresh oil, which will therefore not get ionized or otherwise broken down.

R. A. Marshall: Perhaps Dr Cameron can explain the healing process which goes on when a pitted gear wears itself in service back into a usable condition, because it does seem to me that that is a very interesting special case of lubrication. Many of the problems are accentuated, and yet you do not get, in the instances I am thinking of at least, a catastrophic deterioration and complete failure.

Dr A. Cameron: It is certainly very extraordinary to find gears running in ships completely satisfactorily, yet with nearly 50 per cent of their active surfaces fallen out. I suppose the reason is that they were designed with a large factor of safety, and also when the gears pit they also bed themselves in. Furthermore, by the time the gears have pitted, the flanks will have work hardened.

L. S. Evans: Dr Cameron has put forward some very interesting hypotheses to explain the scuffing and pitting of gears based mainly on the behaviour of the steel and its oxide film under heat and pressure. A check of these hypotheses requires data on the performance, under similar conditions, of steels with compositions that would give a wide range of those properties that, it has been suggested, are important in scuffing, *e.g.* hardness at 250° C, and the tenacity of the oxide film. Few data of this type are available, but some tests made

* Brix, V. H. *Aire. Engng*, 1947, 19, 294.

on the two-ball machine with high chromium martensitic type stainless steel balls give scuffing loads only a third of those obtained with conventional steel balls, although stainless steel would be expected to have the more tenacious oxide film and to retain its hardness better at medium temperatures.

Many workers have reported metallurgical changes in steel after scuffing that could have taken place only at much higher temperatures, *ca* 800° C, and for this reason the transformation temperature of steel has also been suggested as a criterion of resistance to scuffing.

It is possible that the drastic physical and metallurgical changes frequently found on scuffed and pitted gears and disks are sometimes secondary effects that occurred after scuffing rather than the primary effect of oil film breakdown. As a possible example of this, Fig 5 in Dr Cameron's paper shows the formation of a pit in a steel disk; in this, there has been gross distortion of the disk to a considerable depth, a feature not usually associated with pitting.

Dr A. Cameron: I have thought a lot about these high alloy steels, and wondered if the oxide, being mostly Cr_2O_3, which is a very powerful abrasive, causes the surfaces to tear and so weld together, as fresh metal is being constantly exposed.

It must be realized that metallurgical tests of gears that have scuffed must be used with caution, as during scuffing the temperatures are very high.

D. Reece: I would like to raise the question whether in gear operation an oil film carries the load up to the point of seizure or whether in practice the metal surfaces carry a proportion of the load without a separating oil film until the heat generated in the contacting areas becomes excessive.

The point whether surface to surface contact occurs appears to me to be an important one, and I would like to ask Dr Cameron how thermo-electric contact can be observed between two disks which he suggests are separated by an oil film possibly one thousandth of an inch thick?

The results shown in Fig 1 indicate that large variations in load have only a small effect on the resistance obtained; if this resistance is related to the film thickness might we not expect the load to have a bigger effect?

The other point arising from Fig 1 is that the magnitude of the resistance shown is from 1 to 10 ohms. I think Mr Lane has already referred to the fact that an oil film of one thousandth of an inch should have a resistance greater than 1000 ohms.

Is it possible that some degree of surface contact occurs between disks and gears? This would not lead to seizure under conditions of pure rolling, but where sliding and shearing of the surface contacts take place the picture will be different. We have then to consider whether the true function of a gear lubricant is not to carry the load but to modify the contact conditions when sliding is present.

Dr A. Cameron: The thermo-electric potential can be measured quite conveniently if a Wheatstone bridge is used, as no current flows, and hence there is no potential drop across the oil film.

It is difficult to say what the effect of load on the breakdown voltage should be. This paper is exploratory, and in this section, presents only experimental results.

A few tests were done with sliding and rolling combined, the general shape of the resistance–current curve was unaltered. The breakdown voltage dropped slightly, compared with similar conditions of pure rolling, but no systematic experiments have been done, and so the results have not been reported.

The way a lubricant film modifies the pressure distribution is most interesting, and must be investigated. I think it can best be tackled by theory, but it is very complex.

R. A. Fraser: Dr Cameron says in his paper that the origin of the crack shown in Fig 5 is uncertain. Has he considered the possibility that this may have been started by chemical means? One assumes that in these tests there is bound to be a certain amount of air churned into the oil, and it seems that, if you get these high spots with very high pressures and temperatures, rapid oxidation may occur at these points, and I am wondering whether any of these pitting tests have been done in an inert atmosphere, such as nitrogen.

Dr A. Cameron: I think that pits start from these micro-pits. They are $\frac{2}{10{,}000}$ inch deep or thereabouts, and there is no indication of any grain distortion round them. They may have originated as small surface roughnesses or hummocks, which after being very severely distorted, fatigued, fractured, and fell out. They are the most obvious weak spots from which pitting cracks could start.

CONTRIBUTED DISCUSSION

H. Blok: * Despite the efforts of many investigators and the headway made during the past few years, it is thought that even the most advanced theories and experiments about the hydrodynamic lubrication of gears are inconclusive in so far as the problem of determining the potentialities of this kind of lubrication is concerned. The author's suggestion about the probably beneficial effects of the Maxwellian (visco-elastic) behaviour of lubricating oils may well yield a promising line of attack in solving the problem.

It would appear, however, that experimental data about the behaviour concerned are still so meagre, that the new line of attack cannot yet be followed up safely. Moreover, there is still some controversy amongst those who have already attempted to incorporate the effects of visco-elastic behaviour into the basic equations of hydrodynamics. See, for instance, the criticism and corrections by Kuvshinskii † on the equations of Frenkel ‡ and those of Tyabin.§ A very interesting consequence of the author's suggestion is, that, contrary to hydrodynamic predictions in general, surface irregularities could act beneficially.

Referring to the question of adiabatic compression, the author states that there is a rise and fall of 20° to 40° C for the passage of the oil past the point of closest approach of the rubbing surfaces. Presumably he had in mind that in the inlet portion the oil film, up to the film section where film pressure attains its maximum, the heat of adiabatic compression is positive and tends to create a temperature rise, whilst in the remaining outlet portion, this heat becomes negative and thus tends to cancel the rise again.

This opinion, just as that in the similar work by Linke,‖ is shared by the writer, but the latter doubts the

* Professor of Mechanical Engineering, Technological University, Delft, Holland.

† Kuvshinskii. *Zh. eksp. teor. Fiz.*, 1951, **21**, 88–92.

‡ Frenkel. "Kinetic theory of liquids." London: Oxford University Press, 1946.

§ Tyabin. *Zh. eksp. teor. Fiz.*, June 1949, **19**, 559–60.

‖ Linke, R. *Kraftstoff*, 1941, **17**, 213–15.

admissibility of the author's and Lincke's tacit assumption that heat exchange between the oil film and the rubbing surfaces is negligible, which implies that all heat (whether positive or negative) is retained within the inlet portion of the film. This doubt is based on the fact that the oil compressed is bound by comparatively well-conducting surfaces which, moreover, approach each other to within a distance as small as one or a few microns (something like $\frac{1}{10,000}$ inch). If heat exchange should prove to be appreciable, the adiabatic rise and fall of film temperature would be less than indicated by the author.

On the other hand, side by side with the heat of adiabatic compression, the heat generated by viscous friction, which is nowhere negative, is also to be considered. It would appear that the latter heat is more important than the former. Yet, contrary to the opinion of several investigators, it seems that the heat of adiabatic compression is not so small, as compared with the viscous-frictional heat, as to be negligible. Nevertheless, for the purpose of roughly estimating temperature rise in the oil film, it would appear permissible to restrict oneself to viscous-frictional heat. Unfortunately, too little is known at present about the heat exchange between the oil film and the rubbing surfaces, but it is hoped that flash temperature theory, in a form adapted to hydrodynamic lubrication, may shed more light on this question in the not too distant future.

The breakdown voltages of Fig 2 would be indicative of very small film thicknesses, if it may be assumed that specific breakdown voltage is, even under the conditions to be contemplated, not excessively low, say not lower than about 10 kV/cm. In fact, such an assumption would involve film thicknesses of the order of magnitude of at most a few tenths of a micron (something like $\frac{1}{10,000}$ inch).

A similar result has been found by Allen * in his tests on journal bearings, *i.e.* under conditions which, at least from the standpoint of geometry, are quite different from those in gears. There is even a further similarity in the author's and Allen's tests, in that the steep middle portion of the curves in Allen's Fig 108 conforms fairly closely with the author's curves in Fig 2 (note that the position of the axes in Allen's figure is different from that in the author's Fig 2). It would be interesting to verify the possible significance of these similarities.

Fig 4 shows that, as long as the peripheral speeds of the rubbing surfaces are kept constant, it is immaterial in initiating scuffing whether the heat generated in the film is wholly or only partly of mechanical origin. This result might well substantiate the postulate about the constancy of scuffing temperature, provided that the width of the contact area, that would obtain according to Hertz if there were no oil at all, varied only slightly in these tests (according to flash temperature theory as developed by Blok,† it is more precise to say that the square root of the width should not have varied too much). From this point of view, Fig 4 could be made more informative if the author could give some data about the variation of the width concerned.

Dr A. Cameron: Not having access to the work of Kuvshinskii, I cannot effectively comment on his work.

The effect of adiabatic heating may be considerably reduced by rapid heat transfer, but it must certainly add something to the surface temperature of the steel.

As Professor Blok points out, the frictional heat is the most important factor in the temperature rise. It is certainly desirable that a full theoretical investigation be made of this point.

I do not think that bulk figures for the dielectric strength can be used without further study. A lot of work is needed on the dielectric behaviour of very thin films.

The Hertzian areas of the contact can be calculated from the data given in the paper.

J. Mills: While carrying out some tests on the variable slide–roll ratio disk testing machine, which was built by British Timken for Pametrada, it was decided to try the effect of the oil film on the contact resistance of the disks.

A multi-range meter of the AVO type was connected across the disks. Contact was made by steel balls set in the ends of the disk spindles running in contact with phosphor bronze spring blades.

The disks were made of casehardened mild steel, with the mating surfaces ground to approx 20 microinches r.m.s. finish. The face width was 0·250 inch, and the applied load 400 lb.

At zero speed the resistance was just on the scale of the meter, with or without oil. Without oil, *i.e.* with the surface wiped over with trichloroethylene and dried, there was no readable increase of resistance up to 1500 r.p.m. Above this speed, up to 3000 r.p.m. (maximum speed) there was a slight increase up to 2 ohms. This was put down to the fact that vibration set in at about 1500 r.p.m., and it was afterwards discovered that the loading system of the machine was resonant at this speed.

With oil present, however, the change of resistance was most pronounced and definite. It appeared to happen suddenly at quite a low surface speed, 20 to 25 f.p.m., the resistance rising to 15 to 20 ohms. Further increase of speed did not cause a corresponding increase of resistance, and the results were not affected much by variation of the load. The oil used was a light lubricating oil of viscosity 40 sec Red I at 210° F. It was applied to the disks from an oil can while the machine was running.

These results could be obtained with quite a small quantity of oil. If the disks were clean and dry and the machine set in motion at low speed, a spot of oil could be applied to the surface at one point on the 4-inch diameter driven disk and the resistance rise observed on the meter at each revolution.

It appears that the surfaces are separated by the oil film at quite low speeds. It is possible that some degree of metallic contact still exists between the peaks of the surface asperities, but the load being mainly supported by the oil film, the pressure on these will be much less and the area of metallic contact smaller in consequence.

The machine was despatched a short time later, and there was no opportunity of carrying these experiments further.

The method illustrated by Lane (Shell) of connecting an oscillograph across a pair of running gears, might with advantage be applied to a pair of disks. If intermittent metallic contact is occurring between the peaks of the surface finish, it should be possible to show this on an oscillograph, whereas with a moving coil meter the extremely rapid resistance changes are averaged out by the inertia of the movement, and a steady reading obtained.

Another line of experiment might be to treat the disk combination as a capacitor with oil dielectric and fluctuating resistance shunted across it.

It appears that there is plenty of scope for the application of electrical techniques to this, by no means easy, problem.

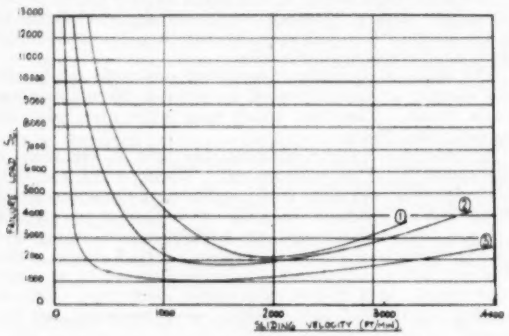
* Allen, C. M. "Mechanical Wear," p. 181–91. Washington: American Society of Metals, 1950.

† Blok, H. *Proc. Discn on Lubrication. Instn. mech. Engrs*, 1937, **2**, 14.

Dr A. Cameron: I am very glad to read Mr Mills' contribution, as the validity of the resistance is clearly vital.

The use of capacity as a means of measuring oil film thickness is attractive, but difficult, as it is very small and there are many stray capacities to contend with.

H. J. Watson: I should like to comment on Dr Cameron's opening remarks that as the rubbing speed between two contacting surfaces increases "the breakdown load rises to a maximum and then drops again." This phenomenon has been observed in disk tests, as he states, but the high build-up of load was found to occur at low rubbing speeds, which may have practical



SCUFFING TESTS WITH OM 88 OIL AND E_n 36 CASE-HARNENED STEEL DISKS

Curve 1. Slide-roll ratio —0·5 on 8-inch dia disk
Curve 2. Slide-roll ratio —1·0 on 8-inch dia disk
Curve 3. Slide-roll ratio 3·0 on 8-inch dia disk

significance when applied to heavily loaded slow-running gears.

Over the more common range of rubbing speeds failure load falls as speed is increased until after a minimum value, as rubbing speed is further increased there is a marked upward rise in the breakdown load. The position of the trough varies with the slide–roll ratio, and possibly with the viscosity of the lubricant, but this has not been fully explored. It would be interesting to learn whether Dr Cameron can offer an explanation for the observed increase in breakdown load.

Dr A. Cameron: The increase in breakdown load at high speeds is very interesting. I have wondered if it can be due to the disks bouncing slightly; even a few microinches, which would be very difficult either to detect or remedy, would make a large difference. Further, can it be that at very high speeds the oil has already got so thin that it has reached virtually a constant viscosity? Hence an increase of speed will start building up a larger oil film?

It is to be hoped that Mr Watson will publish a full description of these tests, as they are clearly of great importance.

R. Tourret: Regarding pitting, surely whether surface cracks or interior cracks are obtained in a particular instance depends on the relative importance of the shear and tensile stresses? If the geometry of the contacting surfaces and the rolling and sliding nature of the contact are such as to give high tensile stresses relative to the shear stresses, surface cracks will appear. This is evidently what happens in marine gears. On the other hand, if the tensile stresses are low relative to the shear stresses, cracks originating below the surface will appear. Ball bearings may be an instance of this. In some applications, the tensile and shear stresses may be equally important, and then both surface and interior cracks will appear, and probably the pits will fall into two depth categories, shallow pits due to surface cracks and deep pits due to interior cracks. This was found to be so with bronze disks operated on the disk wear machine.*

Perhaps Dr Cameron could enlarge upon his reference to pits in marine gears forming stress concentrations and leading to tooth breakage. How much pitting is experienced in service? Is this "arrested" pitting or progressive pitting? When tooth breakage occurs, how often can it be attributed to pitting? Does pitting occur more frequently than scuffing?

For the record, was Fig 5 obtained from a steel disk operated under pure rolling conditions?

Finally, in the experiments in which Way drilled a small hole to relieve the oil pressure in a fatigue crack, how was the tail of the crack located?

Dr A. Cameron: I have always been interested in the work of Evans and Tourret and would like to see an analysis of the stress conditions postulated by them which lead up to the two types of crack, shallow and deep. The cracks we have found in our micro-sections are obstinately surface ones, and the distribution of their depths is quite regular and normal, with no trace of shallow and deep.

The reason for pits forming stress concentrations is simple. If there is a line of deep pits along the pitch line, these can lead to concentrations of stress which are greater than the stresses caused by simple bending at the root of the teeth. The cracks usually associated with pits, extending two or three times the depth of the pit, also increase this concentration of stress.

I am afraid I cannot answer the rest of Mr Tourret's detailed questions for figures, as they are not available to me.

Yes, the disk from which Fig 5 was taken was heavily overloaded and run under conditions of pure rolling. In all such machines, of which Niemann's is a good example, one disk drives another, so that there is always surface traction, even though there is no slip.

Way's paper gives a number of details of his method of locating the tail of the crack.

H. S. Gibson: I would just like to say how interesting we have found Dr Cameron's paper, and evidence of that, of course, is in the discussion, which was raised. As he said himself, at the beginning, he felt sure that there would be a good many comments on this, because the subject has so many unknowns about it, and it is one in which practice seems to be considerably ahead of theory.

The vote of thanks was accorded with acclamation.

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* Evans, L. S., and Tourret, R. *J. Inst. Petrol.*, 1952, **38**, 652.

THE SURFACE AND INTERFACIAL VISCOSITY OF ADSORBED FILMS OF ASPHALT*

By B. C. BLAKEY and A. S. C. LAWRENCE†

In a previous paper,[1] the emulsification of sea water by Admiralty fuel oils was described with special reference to breaking these emulsions. It was pointed out that the function of an emulsifying agent is always that of an energy barrier to coalescence of the droplets of the disperse phase when they collide as a result of their Brownian kinetic motion. The energy barrier may be electrical, as in the case of charged particles mutually repelling one another so that contact does not occur; or mechanical, *i.e.* when each droplet is enclosed in a " bag " of the emulsifying agent of suitable viscosity or rigidity.

In the fuel oil emulsions, powerful evidence was presented to suggest that the energy barrier here was of the mechanical type. It was shown that only the residuum from vacuum distillation of the oil contained the emulsifying agent: that this material, amounting to 23 per cent of the original oil, caused all the emulsifying properties when dissolved in Nujol at 1 per cent concentration. This residual asphalt, when dissolved in a volatile solvent, spread on water to form very thin films, which, when compressed, puckered—thus showing the consistency required for stabilizing the emulsions. It was not possible to decide on qualitative observations whether these films had very high viscosity or whether they also had a small rigidity. This " bag " effect has also been demonstrated by placing a layer of fuel oil, about 8 mm thick, on the surface of water nearly filling a 1-litre beaker; water from a dropping funnel was then run in with the end of the funnel about 1 mm above the water surface; *i.e.* the water was discharged into the oil. This is done at a slow steady streaming rate so that the water sinks through the oil to form a " drop " of some 10 cc separated from the surrounding water by the asphalt membrane. On standing to allow excess oil to rise, this membrane was clearly visible as a light dirty yellow " bag " enclosing the added water. The breaking of emulsions by surface active agents was then most elegantly demonstrated by adding through a pipette a small amount of Teepol at the bottom of the beaker: this diffused upwards and, as soon as sufficient reached the interface, the " bag " burst.

Even so, it was necessary to explain why the emulsifying agent should be adsorbed in sufficient amount at the interface. Gibbs adsorption was ruled out by the absence of any surface active substance capable of giving the necessary dy/dc and, from observation, there was no such significant lowering of interfacial tension. It was therefore suggested [1] that the asphalt was not in true solution but intermediate between this and a normal suspension—any surface activity, however small, would then explain the presence of all the asphalt required at the interface. The work described in this paper gives strong support to this idea.

There still remains the difficulty that there does not appear to be any substance in the oil which has the necessary amphipathic structure to give any surface activity as required, nor indeed is it likely that any hydrocarbon material could have this property. The oil had no acid value, and the small concentration of asphalt required in Nujol solution to show the emulsion stability suggested that the emulsifying agent could not be some small amount of foreign substance in the asphalt but that all or most of the asphalt had the necessary property.[1] Comprehensive chromatographic fractionation of the oil has resolved this problem by showing that the major part of the asphalt contains oxygen in a saponifiable grouping. The whole of the resinous part of the asphalt is not hydrocarbon at all: the polar saponifiable part corresponding with 3 oxygen atoms per molecule of molecular weight ranging from about 1300 to 1970 (for the hard asphalt) gives the amphipathic structure required. This saponifiable material does not show up on the organic acidity test, but has been shown by direct saponification by 2 per cent aqueous–alcoholic potash and by comparing monolayer limiting areas on water and on 10 per cent aqueous KOH.[2]

MEASUREMENT OF INTERFACIAL VISCOSITY

Interfacial (or surface) viscosities were measured by the oscillating bob method;[3] the suspension was a phosphor bronze wire of diameter 0·005 inch and length 25 cm; the bob was of stainless steel 2·41 cm in diameter and moment of inertia of 47·2 C.G.S. units. The period of swing, measured by the usual lamp, mirror, and scale method was 6·9 sec. Hence, the torsional rigidity as given by $\tau = \frac{4\pi^2 I}{t^2}$ was 39·8.

τ, calculated from $\tau = \frac{\pi n r^4}{2l}$, where n is the modulus of rigidity for phosphor bronze equal to $4{\cdot}0 \times 10$ inches, was 40·9. In calculating results, τ was taken as 40 C.G.S. units.

η_s, the surface of interfacial viscosity, is given by the equation:

$$\eta_s = Hp,$$

where $H = \frac{1}{4\pi}\left(\frac{1}{a^2} - \frac{1}{b^2}\right)$ a and b being the radii of the

* MS received 6 April 1954.

† The University, Sheffield.

bob and of the cylindrical container of the liquid (in these experiments, a Petri dish).

For the heavily damped motion where the bob moves slowly back to rest without oscillation

$$p = \frac{\tau}{\frac{dln\phi}{dt}}$$

where ϕ is the residual angle of torque.

Measurements were made by immersing the bob to a standard small depth in the aqueous layer—the viscous drag due to the depth immersed is negligible compared with that due to the surface film when it is one showing surface viscosity. For interfacial viscosity measurements, a standard depth of the oil layer on the water was always used; its contribution to the viscous drag on the bob was also negligible. Since the surface viscosities are anomalous, the figures cited are for an arbitrarily chosen rate of shear corresponding with a scale deflection of 10 cm.

THE FILMS

Following the original observations of the excellent spreading properties of the asphalt on water, it has been found that the films are unimolecular, and force–area curves on water and on 10 per cent KOH solution have been measured for the material and its components fractionated chromatographically. Limiting molecular areas have been determined. For the whole asphalt fraction used in this work, the mean molecular weight was 1600 (cryoscopic in *cyclo*hexane) and the limiting area/molecule 65 A^2.[4] For the surface viscosity of films on water, sufficient asphalt was spread from *cyclo*hexane to form a close-packed film of the smallest molecules present (52·5 A^2). On water after 1 hr the film was plastic, being 1 to 2 surface poises in the range of rates of shear obtainable with the instrument. After 2½ hr it had risen to 5 to 10 surface poises. The ageing effect is not surprising in view of marked ageing increases of consistency frequently observed in emulsions in bulk. On 10 per cent KOH solution, either by spreading on the alkaline surface or by injecting the KOH beneath a film spread on pure water, the final surface viscosity was zero. Using twice as much asphalt, a small η_s was found, but not more than 0·2 to 0·3 surface poise.

INTERFACIAL VISCOSITY

Solutions of 1 per cent of asphalt in toluene, *cyclo*hexane, and hexane were used in turn. One per cent was chosen, as this is well above the minimum concentration required in Nujol to cause all the emulsification properties. The results found are shown in Table I.

Clearly, enormous interfacial viscosities are found when the asphalt is dispersed in a poor solvent and little or no such effect in a good one.

TABLE I

Solvent	On H_2O	On 10% KOH
Toluene	Fluid at first, small after 3 days	None
*cyclo*Hexane	After 1 hr = 0·25, surface poise rising in 24 hr to 1500 surface poises	Very small
Hexane *	After 1 hr too high to measure, *i.e.* above 20,000 surface poises	Very small

* Hard asphalt removed from the hexane solution.

EFFECT OF CRESOL

Cresol and other organic liquids, such as benzyl alcohol and aniline, were found to be good emulsion breakers, but only at uneconomic concentrations.[1] Fig 1 shows the effect of cresol at 2 and 3 per cent (on oil content) upon an emulsion containing 71·1 per cent of sea water. Its effect was attributed to a fluxing of the asphaltic film at the interface, although, of course, there was no evidence whether the film remained there, becoming too fluid to provide an energy barrier, or whether it was dissolved back into the bulk of the oil and no longer adsorbed to the interface. Measurements were made of the effect of cresol upon the bulk viscosity of the fuel oil with the results shown in Fig 2.

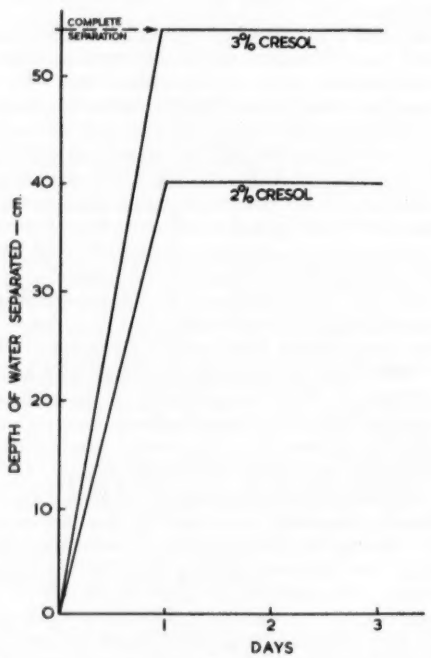


FIG 1

EFFECT OF CRESOL UPON BREAKING EMULSION

The similarity of the initial fall of viscosity with small additions of cresol to an adsorption isotherm is most striking, and the results were interpreted as an initial adsorption of cresol on the asphalt present in the heterogeneous system, fluxing it and reducing aggregation, followed by the later slow normal dilution effect.

Interfacial viscosities were determined for hexane

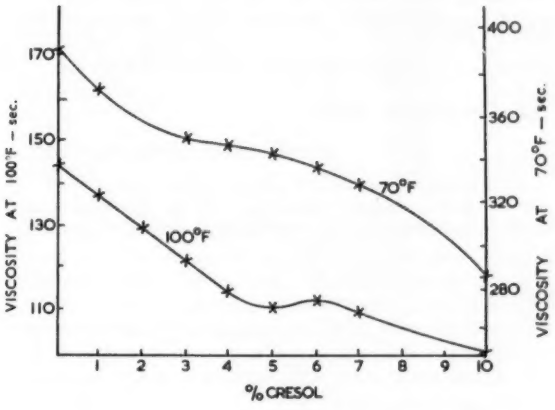


FIG 2

VISCOSITY OF FUEL-OIL–CRESOL MIXTURE

solutions of asphalt to which was added 1, 2, 3, and 5 per cent of cresol with the following results :

TABLE II

Solution	Interfacial viscosity, η_s
1% asphalt in hexane	Plastic : too viscous for measurement *
1% asphalt + 1% cresol	Plastic : too viscous for measurement *
1% asphalt + 2% cresol	*ca* 8000 surface poises at bob-displacement of 3·5°
1% asphalt + 3% cresol	0·75 surface poise
1% asphalt + 5% cresol	0·75 surface poise

* This is greater than 20,000 surface poises, the limit of the apparatus.

It is seen that the enormous non-Newtonian viscosity of the asphalt is not affected noticeably by 1 per cent of cresol : 2 per cent causes a marked reduction, but 3 per cent is needed to reduce η_s to a small value. It is also clear that η_s is not reduced to zero even by 5 per cent of cresol. Cresol against water gave no interfacial viscosity.

It might be suggested that the cresol is not acting as a fluxing agent but as a surface active one displacing the adsorbed asphalt from the interface, just as surface-active agents do. This, however, is unlikely in view of the fact that about 3 per cent, the minimum required to break emulsions completely is also the end of the initial viscosity change in the oil in bulk and of the loss of surface plasticity at the interface. Fig 1 shows the rate of separation of water with time from an emulsion treated with 2 and 3 per cent of Cresol.

Measurements were also made of the distribution ratio of cresol between sea water and fuel oil. Oil containing various amount of cresol was shaken with various volumes of sea water. The water was filtered off from the oil through a wet filter paper and the cresol estimated colorimetrically by adding diazotized sulphanilic acid. A few checks were also made by washing the residual cresol from the oil with dilute alkali and estimating it in the same way. The distribution ratio, *c* oil–*c* water, was 2·3 up to about 2 per cent of cresol in the oil (after shaking with water) but then rapidly falls. This means formally that the cresol is becoming less soluble in the oil, since the aqueous concentration in equilibrium is less than 0·1*N* and still present unassociated.

The final proof, however, is that the cresol, which has no interfacial viscosity, does not reduce η_s to zero but to a limiting value of about 0·75. Although this is very small compared with the enormous values given by the asphalt alone, it is still considerable, being of the same order as that of a close-packed layer of cetyl alcohol.[5] It therefore seems that the action of the cresol lies in " fluxing " the adsorbed film of asphalt and not in displacing it.

The action of 10 per cent KOH in removing interfacial viscosity is particularly interesting, because addition of excess alkali always made breaking by wetting agents much more difficult.

CONCLUSIONS

It has been shown by direct measurement that asphalt in poor solvents forms at a water–hydrocarbon interface a film of extremely large non-Newtonian viscosity. This confirms a previous suggestion that the stability of water in fuel oil emulsions is due to the water being held in " plastic bags " of adsorbed asphalt. The action of cresol as an emulsion breaker is explained by the reduction of interfacial viscosity.

ACKNOWLEDGMENTS

The previous work quoted formed part of researches carried out for Engineer-in-Chief, Admiralty, and Fig 1 is the joint work of W. Killner and A. S. C. Lawrence, carried out at the Admiralty Fuel Experimental Station, Haslar. B. C. Blakey gratefully acknowledges a grant made by D.S.I.R., and financial aid from the Anglo-Iranian Oil Co. is acknowledged with gratitude.

References

[1] Lawrence, A. S. C., and Killner, W. *J. Inst. Petrol.*, 1948, **34**, 821.
[2] A complete account of this work will be published shortly.
[3] Wilson, R. F., and Ries, E. D. " Colloid Symposium Monograph No. 1." p. 145, 1923.
[4] Barby, D., and Lawrence, A. S. C. To be published shortly.
[5] Fourt, L., and Harkins, W. D. *J. Phys. Chem.*, 1938, **42**, 897.

THE INSTITUTE OF PETROLEUM

ANNUAL REPORT

For the Year Ending 31 December 1953

The Council of the Institute sent on behalf of all members, a message of loyalty and devotion to Her Majesty the Queen on the occasion of her Coronation.

MEMBERSHIP

Details of membership as at 31 December 1953 :

	Total Dec. 31 1952	Changes during 1953						Total Dec. 31 1953
		New	Transferred to	Resigned	Deceased	Transferred from	+ or −	
Honorary Members	3	—	—	—	—	—	—	3
Honorary Fellows	5	—	—	—	—	—	—	5
Members	601	29	3	13	5	7	+ 7	608
Fellows	568	38	20	11	4	3	+ 40	608
Associate Members	809	81	2	37	2	8	+ 36	845
Associate Fellows	756	168	25	20	2	6	+168	921
Students	130	19	—	10	—	26	− 17	113
Totals	2872	335	50	91	13	50	+231	3103
Member Companies	179	9	—	5	—	—	+ 4	183

Council are very gratified to announce that for the first time in the history of the Institute the total of corporate members has topped the 3000 mark, and wishes to express its appreciation to the many members who have helped in this effort.

With the advent of the new Economics and Operations Group, and the enlarging of the Institute's periodicals, it hoped that the membership will continue to rise steadily over the years.

DEATHS

The following deaths during 1953 are recorded with regret :

S. Allen (F)
E. M. Bailey (M)
H. W. Barnes (M)
W. H. Edwards (A.M.)
O. H. Griffiths (F)
F. C. Hamilton (F)
R. F. Hamilton (F)
W. H. Kelly (A.F.)
J. F. Miller (M)
C. D. Mitchell (A.M.)
M. Roddan (M)
F. E. Thurland (A.F.)
Dr G. E. Wilson (M)

GENERAL

General Meetings

Thirteen Ordinary General Meetings were held, and Mr H. S. Gibson presented his Presidential Address, after the Annual General Meeting.

The recorded average of attendance at these meetings was ninety-three, approximately 48 per cent of whom were visitors.

Redwood Medal

The 10th Redwood Medal was presented to Dr F. P. Bowden at Manson House on 10 December, when he delivered his paper " The Friction of Non-metallic Solids " to a well attended meeting.

Annual Dinner

The Annual Dinner was held once again at Grosvenor House on 24 February, the principal speaker being Arthur Deakin, Esq., C.H., C.B.E. The attendance was 832.

Summer Meeting

A most enjoyable and successful Summer Meeting was held in June at Buxton. 132 members and their wives attended. A programme of twelve papers, under the general theme "The Post-War Expansion of the U.K. Petroleum Industry," was presented, and all the meetings were very well attended. The book of *Proceedings* will be published early in 1954.

Encouraged by the success of these meetings, Council hope they will become an annual feature of the Institute's activities.

The 1954 Summer Meeting will be held in Llandudno in May.

Economic and Operations Group

Under the chairmanship of Mr O. F. Thompson, a new activity of the Institute was launched in the autumn. Groups covering specialized subjects had been successfully tried in 1939, but the war brought the experiment to an end. The new group covers a wider aspect of the industry, and had a most successful inauguration at an open meeting in October when Mr G. P. Glass presented a paper entitled "The International Economic Situation and the World Oil Industry."

The membership of the group is over sixty, and it is hoped its activities will provide considerable interest to members of the Institute who are interested in the economic field.

Studentship

Mr J. M. Jeffries-Harris was awarded the Institute's Annual Prize at the Imperial College of Science and Technology. No candidate was put forward at Birmingham University for the Student Scholarship, and it is intended to offer two £50 scholarships in 1954.

Aviation Products Data Committee

Following the completion of the draft Data Sheets on Aviation Lubricating Oils mentioned in the last report, the Aviation Fuels Data Sheets have been brought up to date and extended, and drafts have been sent to the Royal Aeronautical Society.

Awards

The Honorary Fellowship of the Institute has been bestowed on Mr T. Dewhurst, original member and Past President, who is still actively associated with the work of the Institute, and will be awarded at the Annual General Meeting. Mr G. H. Coxon has been awarded the Eastlake Medal. This is a new Medal, awarded for long and meritorious service to the Institute, and named in memory of the co-founder of the Institute, the late Mr A. W. Eastlake. Mr C. A. P. Southwell, C.B.E., has been awarded the Cadman Medal, and will deliver the Cadman Lecture in the Autumn of 1954.

Branches and Students Section

All Branches continued to operate successfully during the year. Mr E. A. Evans, the Branch Lecturer, completed his programme of lectures to the United Kingdom Branches, and also lectured in Ireland.

In December a formal request for permission to establish a branch in Australia was approved.

Benevolent Fund

Two applications for assistance have been considered, and grants made, during the year.

Engineering Committee

During the year the Committee completed its study of the draft chapters of the Refining Code, and also revised certain chapters of the Marketing Code.

The Production Code has been completed in draft form, and this draft will be studied in 1954.

Following the recommendation passed by the Committee regarding the inclusion of rules for a "Remotely Dangerous Area" in the Electrical Code, the Electrical Sub-Committee is considering any necessary revisions to the Electrical Code.

A Safety Sub-Committee is in the course of formation.

This Sub-Committee has been set up to give an opportunity for the safety officers of the various oil companies to meet and exchange views, and also to have a body available in the Institute who, if called upon to do so, could make an independent report on fires and accidents which could be available for the oil industry as a whole, and if necessary might be published to offset inaccurate and alarmist reports in the Press.

It is hoped to publish both the Marketing and Refining Codes during 1954.

Finance

The Revenue Account was much more satisfactory than in 1952. As compared with a surplus of £80 in 1952, the surplus in 1953 was over £3000; this was largely due to more satisfactory results from the Publications Accounts, the deficit in that account being reduced by more than £2600.

Income from Corporate and Company members continues to climb steadily with increasing membership.

1950	£16,630
1951	£17,220
1952	£17,830
1953	£18,740

There was a welcome fall in operating expenditure. Salaries and staff pensions rose by about £150, but there were decreases in expenditure on Meetings, legal fees, and general expenses.

An *Ad Hoc* Committee of Council commenced investigations during the year on ways and means of reducing the Institute's expenditure. The cost of printing and publishing our periodicals and books represents the largest single item in the account, so that attention was first devoted to this section of the

Institute's operations. Satisfactory results have accrued largely as a result of the co-operation of the Publications Committee and its Publications Costs Sub-Committee.

The variations in the number and types of publications produced each year makes an overall annual comparison difficult. It is, however, interesting to observe that in 1953 some £5000 less was spent on printing and distributing publications than in 1952. In particular, the cost of printing the 12 issues of the *Journal* was nearly £900 less than in 1952. On the income side, book stocks at £5880 decreased by £850, and £7500 worth of oil measurement publications were sold during the year.

House

The staff at Manson House has changed very little during the year, but following the greatly increased activities of the Publications section, this department has been enlarged.

A tape recording machine has been purchased to record the General Meetings, and this new method has proved most successful. It is now possible to record lectures at Branch Meetings and transcribe them at Manson House for inclusion in the *IP Review*.

Publications

The *Journal* and the *IP Review* have been published at regular monthly intervals and followed the pattern of previous years. Thus, volume 39 of the *Journal* contained the papers which had been read and discussed at Ordinary General Meetings of the Institute and also contributed papers dealing with original researches in petroleum technology. Abstracts of current petroleum literature also continued to be published as an important part of the Institute's *Journal*.

The *IP Review* completed its seventh volume with the twelve 1953 issues, and is a popular journal with the membership of the Institute. In addition to containing papers read at some of the Branches meetings and reports of those meetings, this publication also contained contributed technical articles of general interest to members and special articles for students of petroleum technology.

During 1953 considerable attention was given to the format of both the Institute's periodical publications. It had been realized for a long time that a larger page size would have many advantages, and it was decided that from the beginning of 1954 the *Journal* and the *IP Review* should be produced on a larger page.

Other Publications

The publication of the Metric Edition of the "ASTM/IP Petroleum Measurement Tables" in the autumn completed the series of three volumes on this important aspect of the petroleum industry. The companion volumes—British and American—had been published in 1952 by the Institute and by the ASTM respectively. The three volumes are a monument to the co-operative efforts of the two bodies in the field of international standardization in which Mr H. Hyams has played the leading role.

Other volumes published during the year were the 13th edition (covering 1951) of "Reviews of Petroleum Technology" and the 13th edition of "Standard Methods for Testing Petroleum and Its Products." As regards the former, it had been apparent that the popularity of this review had lessened during recent years, and special consideration was given to the future of the reviews. It was eventually decided to change the character and style of the book and to review progress in the industry triennially rather than annually. Therefore, the next volume in this series will be issued in 1955 to cover in general the period 1952–54.

Meetings

In addition to the normal monthly Ordinary General Meetings of the Institute, a conference on Applied Mass Spectrometry was held at the end of October. A considerable and important discussion followed the delivery of the Paper, and the full report will be published by the Institute, in the form of a book, during 1954.

Library

As a result of much hard work by the Library Sub-Committee considerable progress has been made in the re-classification of the books as the basis for a card catalogue and the possible issue of a printed catalogue. There was an increase in the use made of the Library by members and others interested in the subject of petroleum.

Public Relations

During the year the Public Relations Committee has considered the policy of the Institute in regard to public relations.

The present feeling is that the work of the Public Relations Committee should be primarily on behalf of the Institute, and that its sphere would not include the undertaking of public relations work on behalf of the industry. It is felt that the work of the Institute of Petroleum is not strictly comparable with that of the API, but a study of the activities of the latter is being made so that advice on this point can be more definite.

Research

The Research Committee has continued to foster research work at Universities on problems related to petroleum. The Hydrocarbon Research Group through its various panels has sponsored work at three universities on the chemistry of hydrocarbons, at three universities on developments in spectroscopy and at four universities on developments in mass spectroscopy. A co-operative programme involving

a number of industrial and university laboratories has been undertaken to ascertain the reliability of mass spectroscopic analysis and a successful Conference on Mass Spectrometry was organized during the year.

The Research Group No. 2 has co-operated with the Medical Research Council in investigations of the biological activity of petroleum fractions, and has sponsored a programme of research at Birmingham University.

Standardization

Very careful consideration has been given to the possibility of issuing "Standard Methods" in loose-leaf form, but this does not appear to be practicable at the present time.

The 13th edition of "Standard Methods" was issued during November, and work is proceeding on the 14th edition, which it is hoped to publish early in 1955.

There has been increasing contact and exchange of views during the year between corresponding groups of the Institute and of the ASTM. During an extended visit of Dr F. D. Tuemmler of ASTM full discussions were held with a number of Sub-Committees and Panels of Standardization Committee. The third (metric) volume of the joint ASTM/IP Petroleum Measurement Tables was issued during the year.

Two successful symposia were held on "The Examination of Used Lubricating Oils" and on "The Engine Testing of Lubricating Oils" respectively.

ACKNOWLEDGMENT

Once again Council records with great pleasure how well served the Institute has been by its Staff, under the able leadership of the General Secretary and the Editor.

By Order of the Council,

C. CHILVERS,
Honorary Secretary.

March 1954.

THE INSTITUTE

(A Company limited by Guarantee

BALANCE SHEET AS

1952 £		£ s. d.	£ s. d.
	Capital of the Institute under Bye-Laws 36, 44, and 45 :—		
	Life Membership Fund—		
1,009	As at 31 December 1952	1,008 17 9	
	Entrance and Transfer Fees—	£ s. d.	
	As at 31 December 1952	6,551 12 9	
	Add Receipts during 1953—		
	Entrance Fees	397 19 0	
	Transfer Fees	13 13 0	
6,552		6,963 4 9	
	Profit on Sale of Investments—		
258	As at 31 December 1952	257 19 4	
	Donations—		
326	As at 31 December 1952	326 5 0	
8,145			8,556 6 10
5	**T. C. J. Burgess Prize Fund**		5 0 0
1,702	**General Reserve (previously War Contingencies Reserve)**		1,702 0 11
	Revenue Account :—		
	As at 31 December 1952	10,456 2 0	
	Add Surplus for year to date	5,377 12 4	
10,456			15,833 14 4
	Subscriptions Received in Advance :—		
	Members' Subscriptions for 1954	1,912 10 0	
	Members' Subscriptions for 1955	7 7 0	
	Members' Subscriptions for 1956	4 4 0	
	Member Companies' Subscriptions for 1954	1,442 7 0	
	Journal Subscriptions for 1954	1,062 15 6	
	Journal Subscriptions for 1955	20 17 0	
	Journal Subscriptions for 1956	2 13 3	
2,811			4,452 13 9
	Current Liabilities and Provisions :—		
	Provision for Pension	350 0 0	
	Sundry Creditors and Accrued Charges	4,989 10 5	
	World Petroleum Congress	390 9 9	
	Entertainment Account—	£ s. d.	
	As at 31 December 1952	347 13 2	
	Add Excess of Receipts over Expenditure during year to date	356 4 3	
		703 17 5	
5,766			6,433 17 7
	Sum Set Aside for Grants to Branches and Students' Section—unallocated :—		
	Balance as at 31 December 1952	167 0 0	
	Add Amount set aside during year	500 0 0	
		667 0 0	
167	*Less* Grants made during year	572 17 0	
			94 3 0
£29,052			£37,077 16 5

AUDITORS' REPORT TO THE MEMBERS

We have examined the above Balance Sheet and annexed Revenue Account and report that we have obtained all the
In our opinion proper books of account have been kept by the Institute, so far as appears from our examination of those
best of our information and according to the explanations given to us, the accounts give the information required by the
affairs at 31 December 1953, and the Revenue Account gives a true and fair view of the revenue for the year ended on that

88 LEADENHALL STREET,
LONDON, E.C. 3.

9 *March* 1954.

OF PETROLEUM

and not having a Share Capital)

AT 31 DECEMBER 1953

1952 £		£ s. d.	£ s. d.
	Investments :—		
	On account of Capital, at cost—		
	£525 0 0 3% Savings Bonds, 1955/65	525 0 0	
	867 8 6 2½% Bristol Corporation Redeemable Stock, 1955/65	845 17 7	
	150 0 0 3% Smethwick Corporation Redeemable Stock, 1956/58	151 4 9	
	150 0 0 3% Luton Corporation Redeemable Stock, 1958	151 6 7	
	806 8 3 3% Manchester Corporation Redeemable Consolidated Stock, 1958	845 17 7	
	600 0 0 3% Bristol Corporation Redeemable Stock, 1958/63	597 7 3	
	664 6 6 3% London County Consolidated Stock, 1920	481 10 6	
	400 0 0 3% Metropolitan Water Board " A " Stock, 1963	346 10 7	
	193 0 0 3% British Gas Guaranteed Stock, 1990/95	154 8 6	
	156 9 8 3% British Transport Guaranteed Stock, 1978/88	105 4 9	
	461 0 0 2½% Funding Loan, 1956/61	461 15 6	
	500 0 0 2½% Defence Bonds	500 0 0	
5,166			5,166 3 7
	(Market Value at 31 December 1953, £5035.)		
2,979	Cash on Deposit with Post Office Savings Bank		3,390 3 3
8,145			8,556 6 10
	On account of Revenue, at cost—		
	£2,942 2 9 3% Savings Bonds, 1955/65	2,975 0 0	
	2,000 0 0 3% Savings Bonds, 1960/70	2,000 0 0	
4,975			4,975 0 0
	(Market Value at 31 December 1953, £4,699.)		
	Office and Library Furniture :—		
	Valuation being Net Amount standing in the Company's books at 1 July 1948		
	less Sales	221 10 8	
	At Cost	2,108 2 5	
		2,329 13 1	
	Less Aggregate Depreciation	761 12 1	
1,517			1,568 1 0
14,637			15,099 7 10
	Current Assets :—		
6,716	Stock of Publications in hand as certified by the General Secretary	5,876 18 6	
3,570	Sundry Debtors and payments in advance, including Income Tax recoverable	6,777 4 4	
—	*Subscriptions in arrear (not valued)*	— — —	
	Cash on Deposit with Post Office Savings Bank— £ s. d.		
1,149	General Account 454 9 7		
4	World Petroleum Congress 390 9 9		
		844 19 4	
	Cash at Bank—		
—	Deposit Account 3,000 0 0		
2,028	Current Account 4,090 9 0		
348	Entertainment Account 788 17 5		
		7,879 6 5	
600	Cash in hand	600 0 0	
			21,978 8 7
£29,052			£37,077 16 5

OF THE INSTITUTE OF PETROLEUM

information and explanations which to the best of our knowledge and belief were necessary for the purposes of our audit. books. The Balance Sheet and Revenue Account are in agreement with the books of account. In our opinion, and to the Companies Act, 1948, in the manner required, and the Balance Sheet gives a true and fair view of the state of the Institute's date.

SMITH & WILLIAMSON,
Chartered Accountants.
Auditors.

THE INSTITUTE

(A Company limited by Guarantee

REVENUE ACCOUNT FOR THE

1952 £		£	s.	d.	£	s.	d.
	To **Administrative Expenses :—**						
9,071	Staff Salaries and National Insurance	9,419	19	2			
760	Staff Pension Scheme Contributions	861	10	3			
9,831		10,281	9	5			
3,790	*Less* Applicable to Publications	4,743	9	0			
6,041					5,538	0	5
837	Printing and Stationery	816	17	6			
720	General Postages	686	11	8			
242	Telephones, Cables, and Travelling Expenses	283	10	1			
		1,786	19	3			
—	*Less* Applicable to Publications—one-third	595	13	1			
					1,191	6	2
73	Audit Fee	73	10	0			
114	Legal Fees	35	17	0			
461	General Expenses	188	0	1			
29	Insurance	33	4	9			
					330	11	10
8,517					7,059	18	5
	,, **Establishment Expenses :—**						
	Rent	2,500	0	0			
	Cleaning, Lighting, and Heating	458	4	10			
	Repairs and Maintenance	44	19	7			
		3,003	4	5			
	Less Applicable to Publications—one-fourth	750	16	1			
2,253					2,252	8	4
	,, **Meetings :—**						
595	Hire of Hall, Pre-prints, Reporting, etc.				480	14	1
500	,, **Sum Set Aside for Grants to Branches and Students' Section**				500	0	0
	,, **Sundries :—**						
	Library Expenses	89	9	3			
	Subscriptions to Societies	69	13	8			
	Scholarship Awards	100	0	0			
	Depreciation of Furniture (10%)	174	4	6			
575					433	7	5
5,781	,, **Publications Revenue Account—Deficit for year**				3,117	0	4
80	,, **Balance, being Surplus Revenue for year**				5,377	12	4
£*18,301*					£19,221	0	11

OF PETROLEUM

and not having a Share Capital)

YEAR ENDED 31 DECEMBER 1953

1952 £		£	*s.*	*d.*
9,149	By Members' Subscriptions received for 1953	9,894	16	0
119	,, Members' Subscriptions in Arrear, received during year	155	4	0
8,567	,, Member-Company Subscriptions received for 1953	8,680	17	6
10	,, Member-Company Subscriptions in Arrear, received during year	10	10	0
20	,, Special Subscription	20	0	0
436	,, Interest and Dividends received (Gross)	459	13	5
£18,301		£19,221	0	11

PUBLICATIONS

Revenue Account for the Year ended 31 December 1953

	£	s.	d.		£	s.	d.
To Stock in Hand at 1 January 1953	6,715	10	0	By Advertising	5,374	17	11
„ Dispatch Expenses	737	7	6	„ Journal	3,023	2	3
„ Journal	8,038	11	10	„ IP Review	358	11	7
„ IP Review	2,395	0	9	„ Standard Methods	3,279	16	0
„ Abstracts	397	12	6	„ Reviews of Petroleum Technology	1,171	2	10
„ Standard Methods	1,915	7	10	„ Electrical Code	137	13	0
„ Reviews of Petroleum Technology	1,026	5	7	„ Mass Spectrometry	286	3	3
„ Tables for Measurement of Oil	3,779	18	7	„ Petroleum Measurement Manual	817	10	0
„ List of Members	371	2	6	„ Tables for Measurement of Oil (British Edition)	3,537	14	0
„ Other Publications	48	0	10	„ Tables for Measurement of Oil (Metric Edition)	4,025	7	6
„ Publicity	80	2	3	„ Oil Shale Conference Proceedings	113	7	0
„ Salaries, National Insurance, and Pension Scheme Contributions	4,743	9	0	„ Other Publications	493	15	4
„ Proportion of Administrative Expenses	595	13	1	„ Stock in Hand at 31 December 1953	5,876	18	6
„ Proportion of Establishment Expenses	750	16	1		28,495	19	2
„ Bad Debts written off	18	1	2	„ Balance, being Deficit for year carried to Revenue Account	3,117	0	4
	£31,612	19	6		£31,612	19	6

HYDROCARBON RESEARCH GROUP

Revenue Account for the Year ended 30 September 1953

	£ s. d.	£ s. d.		£ s. d.
To Grants :—			By **Voluntary Contributions from Members of the Group**	8000 0 0
King's College	830 0 0		,, **Balance, being Deficiency for year**	244 7 6
University of Oxford	1,030 0 0		For convenience in administration the Accounts of the Group are closed as at 30 September each year	
University of Birmingham	1,225 0 0			
Bedford College	1,160 0 0			
Queen Mary College	1,995 0 0			
University of Liverpool	500 0 0			
University of Cambridge	450 0 0			
		7,190 0 0		
,, **Honoraria**		682 10 0		
,, **General Expenses**		21 17 6		
,, **Wages**		350 0 0		
		£8,244 7 6		£8,244 7 6

Statement of Funds at 30 September 1953

	£ s. d.	£ s. d.		£ s. d.
Sundry Creditor—The Institute of Petroleum		262 10 0	**Contribution due, not yet received**	1,000 0 0
Revenue Account :—			**Cash at Bank on Current Account**	417 18 3
Balance at credit at 30 September 1952	1,399 15 9			
Deduct Deficiency for year	244 7 6			
		1,155 8 3		
Note : The Group has agreed to indemnify the Institute of Petroleum for any loss, up to £250, resulting from the publication of "Mass Spectrometry."				
		£1,417 18 3		£1,417 18 3

We have examined the above Revenue Account and Statement of Funds with the books and vouchers of the Group and find them to be in accordance therewith.

88 Leadenhall Street,
London, E.C. 3.
9 *March* 1954.

Smith & Williamson.
Chartered Accountants.
Auditors.

CARCINOGENICITY RESEARCH FUND

Statement of Funds as at 31 December 1953

	£	s.	d.		£	s.	d.
Balance of Sum Received from the Petroleum Board (during 1947)	1,450	0	0	**Cash at Bank on Current Account**	452	15	7
Interest on Bank Deposit Account	2	15	7	**Cash at Bank on Deposit Account**	1,000	0	0
	£1,452	15	7		£1,452	15	7

We have examined the above Statement of Funds with the books and vouchers of the Fund and find it to be in accordance therewith.

88 Leadenhall Street,
London, E.C. 3.
9 *March* 1954.

Smith & Williamson.
Chartered Accountants.
Auditors.

CADMAN MEMORIAL FUND

Income and Expenditure Account for the Year ended 31 December 1953

	£	s.	d.	£	s.	d.		£	s.	d.
To Balance at 31 December 1953 :—							**By Balance at 31 December 1952**	3,333	1	8
Cash at Bank on Deposit Account	500	0	0				**,, Interest received gross**	83	5	9
Cash at Bank on Current Account	186	7	5							
£2,730 3% Savings Bonds 1965/75	2,730	0	0							
(Market Value at 31 December 1953—£2,443)				3,416	7	5				
				£3,416	7	5		£3,416	7	5

We have examined the above Income and Expenditure Account with the books and vouchers of the Fund, and find it to be in accordance therewith.

88 Leadenhall Street,
London, E.C. 3.
9 *March* 1954.

Smith & Williamson.
Chartered Accountants.
Auditors.

BENEVOLENT FUND

Income and Expenditure Account for the Year Ended 31 December 1953

1952 £		£	s.	d.	£	s.	d.	*1952* £		£	s.	d.
—	**To Grants paid**				65	0	0	*2,942*	**By Balance at 31 December 1952**	3,092	0	9
—	**,, Sundry Expenses**					4	0	*96*	**,, Subscriptions and Donations received during year**	115	6	0
	,, Balance at 31 December 1953 :—							*54*	**,, Interest received gross**	56	5	0
	Represented by :—											
	Cash at Bank on Current Account	248	7	9								
	Cash at Bank on Deposit Account	900	0	0								
	£500 3% Defence Bonds	500	0	0								
	£1550 2½% Defence Bonds	1,550	0	0								
3,092					3,198	7	9					
	(Market Value of Investments at 31 December 1953, £2,050)											
£3,092					£3,263	11	9	*£3,092*		£3,263	11	9

We have examined the above Income and Expenditure Account with the books and vouchers of the Fund and find it to be in accordance therewith.

88 Leadenhall Street,
London, E.C. 3.
9 *March*, 1954.

Smith & Williamson.
Chartered Accountants.
Auditors.

THE INSTITUTE OF PETROLEUM

FORTY-FIRST ANNUAL GENERAL MEETING

THE Forty-first Annual General Meeting of the Institute of Petroleum was held at 26 Portland Place, London, W.1, on 21 April 1954. Mr H. S. Gibson, C.B.E., M.A., M.I.Mech.E., presided.

The notice convening the meeting was read by the General Secretary, and the minutes of the Fortieth Annual General Meeting held on 21 April 1953 were read, confirmed, and signed by the President.

ELECTION OF OFFICERS FOR THE SESSION 1954–55

President

On the motion of H. S. Gibson, seconded by A. R. Stark, the Council's nomination of Lt.-Col. S. J. M. Auld, O.B.E., M.C., D.Sc., as president for the session 1954–55 was approved with acclamation.

Vice-President

H. S. Gibson proposed and D. L. Samuel seconded that Professor F. Morton be elected a vice-president for a term of three years. This was carried unanimously.

Council

The President announced that five nominations had been received to fill five vacancies on the Council and declared the following to be elected :

W. S. Ault	E. J. Sturgess
Dr E. B. Evans	O. F. Thompson, O.B.E.
D. L. Samuel	

Honorary Treasurer

A proposal that G. H. Coxon be re-elected Honorary Treasurer for the ensuing session was made by A. R. Stark, seconded by D. L. Samuel, and carried without dissent.

Honorary Secretary

In proposing that C. Chilvers be re-elected as Honorary Secretary for 1954–55, H. Hyams referred to the very valuable services which Mr Chilvers had given to the Institute as Honorary Secretary. Seconding the motion, F. L. Garton endorsed the remarks made by Mr Hyams, and the proposition was carried unanimously.

Ex-officio Members of Council

It was announced by the President that the following had been nominated to represent the Branches as ex-officio members of Council :

H. H. Ballard	*Northern Branch*
S. A. Berridge	*Fawley Branch*
W. H. Davies	*London Branch*
N. W. Grey	*South-eastern Branch*
E. J. Horley	*South Wales Branch*
W. M. Stirling	*Scottish Branch*

It was proposed by F. L. Garton and seconded by Dr E. B. Evans that these nominations be accepted and this was carried unanimously.

MEMBERS ELECTED OR TRANSFERRED

The list of Honorary Members, Honorary Fellows, Members, Fellows, Associate Members, Associate Fellows, and Student Members elected or transferred during the year 1953 was presented and tabled.

REPORT OF COUNCIL

H. S. Gibson, proposing the adoption of the report, said : Everyone has had a copy of the Annual Report of Council for the year 1953, but I would like to say a few words in regard to the main features of the Institute's progress in that year.

The Institute has a great duty to perform, both to its members and the industry, and one can see from this report how that work has been begun. The membership has steadily increased and the total number of corporate members now exceeds 3000. The Council are most appreciative to the members of the Institute who have helped in increasing this membership.

A very successful and enjoyable Summer Meeting was held at Buxton, and it is hoped that these summer meetings will now become regular functions of the Institute. The summer meeting this year is to take place at Llandudno, and it is felt that this will be even more successful than the one at Buxton. I may add that the published proceedings of the Buxton meeting have been received with a considerable amount of interest, not only from members of the Institute, but also from members of the industry outside the Institute, and such publications do a great deal to raise the standard of the Institute with the industry and with all persons interested in petroleum.

During the past year, an Economics and Operations Group was formed, the first of the groups to extend the activities of the Institute, and so broaden its basis. This was formed under the leadership of O. F. Thompson, and several successful meetings have been held on a subject which, in the past, has not received the attention which it really deserves. We anticipate that in the near future other groups will be formed.

Branches of the Institute in various parts of the world continue to flourish, and during the year a new one was formed in Australia.

The publications activities of the Institute were very extensive, and a greater number of publications have been published than in any previous year. Particular

mention must be made, of course, of the success of the oil measurement tables which have been published in collaboration with the ASTM. When one considers the very small staff on the publications side of the Institute, one realizes the extent we are indebted to G. Sell, our Editor, and I think the way we have increased publications reflects very great credit on him.

The Research and Standardization Committees have been very busy during the year, and our relations with the great American standardizing body, the ASTM, have never been more cordial. Those relations depend entirely on personal contacts. It is of the greatest importance to the Institute that personal contact is maintained not only with the ASTM but also with all other bodies who have similar interests in other parts of the world.

I now move that the Annual Report for the year 1953 be received and adopted.

Mr. S. G. Burgess seconded the motion, which was carried unanimously.

ACCOUNTS FOR THE YEAR 1953

H. S. Gibson : Mr G. H. Coxon, the Honorary Treasurer, is unable to be with us today to give his usual review of the financial position of the Institute. The financial side is extremely important if we are to carry on the Institute's activities with success, and so I would like to ask Mr Hyams, Chairman of the Finance Committee, to report on the accounts and to move their adoption.

H. Hyams : Mr President, ladies, and gentlemen—I, too, wish to express our great regret that our Honorary Treasurer, Mr Coxon is not, this year, able to present the Annual Accounts to the members. I know how much he would have enjoyed giving you a view of the happy condition of our finances as reflected in the 1953 accounts. Mr Coxon has been unwell for some time, but is continuing to make excellent progress toward recovery.

I would like to highlight perhaps three or four of the main items as they appear in the 1953 accounts.

With the increase of Corporate membership to over 3100 at the end of last year, it is pleasing to note that we now have a total income of over £10,000 from our corporate members, about £1200 more than two years ago.

We are grateful to the 183 member companies for their continued regular support. In 1953 we received nearly £8700 of income from this source.

On the expenditure side, our direct operating expenditure last year totalled nearly £17,000, of which £10,280 went on salaries and pensions. It is good to know that despite ever rising all round costs, we managed to keep our expenditure in operating the administrative machine at Manson House down to a very reasonable level. Members will be interested to note that we spent nearly £1500 last year on grants to our ten home and overseas branches; on scholarships; on the stocking of the library; and on expenses of running our many meetings and symposia during the year.

A brief study of the Publications Account, to which Mr Coxon referred in last year's review, will reveal the wide range of our activities in the field of publications. In 1953, considerable time and intensive study was devoted to planning the much improved *Journal* and *IP Review*. We hope to be able to advise members in twelve months time how fruitful, financially, the labours of those who work so hard in this connexion have been. But I would be remiss in my duty if I did not, at this Annual General Meeting, praise the efforts of the Publications Committee and the Publications Costing Sub-Committee for the steps they took last year which resulted in a substantial reduction in the cost of producing the *Journal* and the *IP Review*. Their efforts have been successful in other directions, which are also reflected in a considerable improvement in the Publications Account as compared with 1952.

In general, our increased revenue from subscriptions and the improved Publications Account have been mainly responsible for the surplus in our Revenue Account of £5377, compared with only £80 in 1952. I am happy therefore to be able to report that our Revenue Reserve has gradually ascended and it now stands at £5500, apart from about £11,500 of Capital Reserves. Those responsible will, however, continue to watch the Institute's finances most closely, in order that our financial position may enable us to give efficient and ever improving services to our members and to the industry.

I am therefore very pleased indeed to move the adoption of the Institute's accounts for the year 1953.

The motion was seconded by Mr A. C. Hartley and carried unanimously.

AUDITORS

On the proposal of H. Hyams, seconded by R. B. Southall, Messrs Smith and Williamson were appointed as auditors at a remuneration to be fixed by the Council.

INDUCTION OF NEW PRESIDENT

H. S. Gibson : If there is no other business for this Annual General Meeting, I now proceed to the induction to the Chair of our new President. Lt.-Col. Auld needs no introduction from me, because he is well known to everyone; for the work he has done, and particularly the very valuable services rendered to the Institute over many years.

It is, I think, extremely important that the presidency of the Institute should now be taken over by someone like Lt.-Col. Auld. I have found that when one is President, one looks on the work of the Institute from an angle somewhat different from that

of an ordinary member. The Institute is, I think, entering upon a very important stage of its existence. It began, as we all know, as the Institution of Petroleum Technologists. Then, with great foresight, the Council decided in 1938 that its basis should be broadened and it should become the Institute of Petroleum. The war unfortunately caused a hiatus in that proceeding, and it is only now that the war is over, that we are able to proceed with that change. It is singularly appropriate that Lt.-Col. Auld, who was president at the time when the Institute of Petroleum was formed, should now again occupy the Chair when that decision is being put into effect.

There is a great deal of work to be done in carrying forward the affairs of the Institute, and I personally foresee a great future ahead, a future in which the Institute will not only look after the professional interests of its members, but also the broad interests of the industry, because the petroleum industry is so small. With a relatively small membership we cannot proceed in the same way as other technical institutions which are very broadly based with industries which cover the whole country. The petroleum industry is becoming increasingly important, and in the next ten or twenty years is, I feel, going to grow to an extent probably not dreamt of today. That is why I say that the immediate future of the Institute is going to be of extreme importance, and I cannot think of anyone better fitted than Lt.-Col. Auld to occupy the Presidential Chair in this coming year when these changes will begin to take effect.

Lt.-Col. S. J. M. Auld : Thank you very much, Mr Gibson.

Ladies and gentlemen, I am, as you may imagine, deeply sensible of the honour that has been conferred on me by my election to the presidency of the Institute. I have often wondered during the last seventeen years whether I had justified my previous occupation of the chair, so you can well understand that my emotions at the moment are rather mixed. All I can say is that I shall do my best, and I know that I have the help and support of all of you, and especially the help, support, and stimulus of my friends and predecessors in this office, of whom I count amongst the most sincere the outgoing president. We have to thank him very much for what he has done for us during his term of office, and I am going to ask Dr E. B. Evans to express those thanks for all of us.

Dr E. B. Evans : We have once again to express our thanks to a retiring president. In a sense, however, presidents never really retire because, under the constitution of the Institute, they remain active and vigorous members of council for a very long time afterwards.

The amount of work which a two-year term of presidency involves is very considerable and perhaps only fully appreciated by those who, like members of council and committees, are in close association with the president. It is really amazing how much time so many of our presidents find to give to the affairs of the Institute. Presidents are usually very busy men, quite apart from their presidential duties, and in the case of Mr Gibson we know that he has great responsibilities in the field of Middle East oil production. It is all the more extraordinary that he has managed to give so much time and put in so much work, thought, and energy to Institute matters as he has in the past two years. I know we are all very grateful to him for the efforts he has made.

Some of the work of a president lies in quiet guidance of the policy of the Institute; some of it is more spectacular, such as the arrangement of the recent, very successful Annual Dinner—traditionally a " president's function." All these things, however, add together to put an enormous burden on the occupant of the Chair, and this two years service represents a very large contribution to the Institute's welfare and prosperity.

We have been extremely fortunate in our presidents, in that so many of them have combined scientific and technical achievement with wide experience and reputation in world affairs. Mr Gibson has been outstanding in these respects, and for that reason also he has done much to raise the status of the Institute not only in the oil industry but in other industries in the United Kingdom also.

May I thank you, Mr Gibson, on behalf of all of us for the immense amount of work you have done for us and express the hope that you have enjoyed your term of office as much as we have enjoyed having you as our president.

H. S. Gibson : Mr President, Dr Evans, I thank you very much indeed for those remarks which I feel are far too kind. Personally, my own remembrance is one of sins of omission, because there are so many things which I know I could well have done in my term of office, and which I have not done, and I have really enjoyed presiding at meetings, and it has given me an insight into the affairs of the Institute, which I find invaluable. So much so, that I can assure my fellow members, that so far as I am able, I shall continue to support the Institute in every way I possibly can in the future. Thank you very much.

AWARD OF THE EASTLAKE MEDAL TO G. H. COXON

Lt.-Col. S. J. M. Auld : Ladies and gentlemen, it has been apparent to us for a long time that suitable and concrete methods should be found of expressing our thanks to those of our own members who, by application and devotion, make it possible for the Institute to continue. It is therefore a great pleasure to me that the first overt activity in my term of office is to honour two of our most notable members.

For that purpose the Eastlake medal was instituted by the council in 1953, and is awarded for long and meritorious service to the Institute. It is therefore

not only conformable to that, but also most appropriate, that the first recipient should be G. H. Coxon. His personal absence today is due to his health, which he is recovering, and it is fine to think that we shall have him back with us before very long. G. H. Coxon, is one of those men, all too infrequent, who have not only the instinct and ability to " rally around," but who possess that continued determination to see a thing through, and if I were asked to sum up my opinion of him, it would be along those lines every time.

Mr Coxon joined the Institute away back in 1918; he was a Member of Council in 1936, became a vice-president in 1942, was elected to the Finance Committee in 1936, served as its chairman from 1946 to 1947, and has been Honorary Treasurer from that date. In addition, he has served on the Election, the House, the Publications, and the Public Relations committees, and I would remind you that in 1946 he occupied the chairmanship of Council itself—that was during Sir Andrew Agnew's second year of office as president.

It has been established by Council that the Eastlake medal shall not be presented to a president or to a past-president of the Institute, so this award is one thing that we get on the credit side of Mr Coxon's illness, in that it makes him eligible for this honour, which we are now conferring upon him. It is indeed a great pleasure to me to be in the chair when that honour is bestowed. The medal itself is here to be seen. It is a very beautiful thing, and with the agreement of the outgoing president, I propose (and I hope I have your sanction) that a small delegation of members of the Institute should visit Mr Coxon at an early date and present it to him personally.

AWARD OF HONORARY FELLOWSHIP TO THOMAS DEWHURST

Lt.-Col. S. J. M. Auld : The other honoured member is our friend Mr Thomas Dewhurst, a Past-President, and not only a founder member of the Institution of Petroleum Technologists, as it was at that time, but one who had given his agreement to become a member prior to the actual foundation. He therefore joined the Institution in 1913, and was elected to council just thirty years ago, in 1924. He became a vice-president in 1931 and served as President, as we all know, from 1933 to 1935. One of our quite naturally limited band of geologists, I always feel that Mr Dewhurst has brought with him that width, that broadness of perspective, and that depth of understanding which would seem appropriate from his profession. His acumen, combined with a never failing benignity and a refreshing newness of outlook, is most attractive, and it is a fine thing to know, as many of us do, that the admiration which we have for him is shared by our friends on the Continent of Europe and in America. Things are not always too easy at some of the gatherings, for example of the World Petroleum Congress. Fresh people come in, new nations are being represented, and views are not always in accord, but it has been our experience that during his term of presidency of the first World Petroleum Congress and thereafter on the Permanent Council, these attributes of Mr Dewhurst have bridged over many difficulties. May I add that his invariably trim and gallant bearing, and his ability to tell a story appropriately and at the right time have put many things on the right footing and have redounded to the credit of the Institute and of his country.

Mr Thomas Dewhurst : Mr President, ladies, and gentlemen, I thank Council for this award, which I value highly, and I thank you, sir, for your generous tribute.

When the Institute was founded, the membership comprised twenty-nine founder members, and some fifty other members of various grades who had agreed to become such prior to the foundation. I agreed in 1911 to become a member of the Institute if and when it was formed.

The advantage of that early connexion with the Institute was that one became acquainted with some of the pioneers of the oil industry in the United Kingdom, particularly the early petroleum technologists. I have been privileged to know personally every president and nearly every officer of the Institute since the foundation, and to have known these men, and to have seen the Institute grow from infancy to its present stature, has been a rich and a rewarding experience.

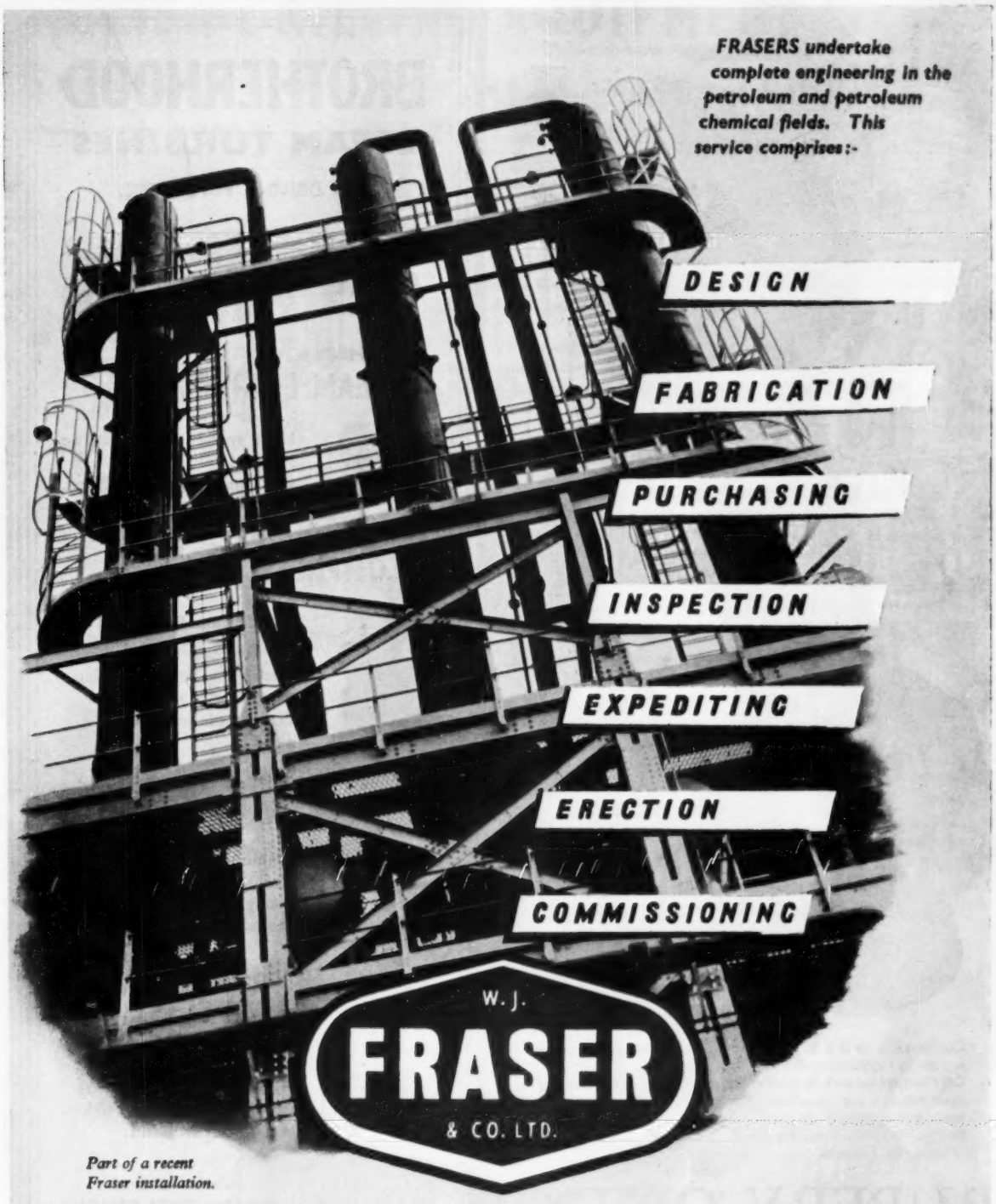
Each of the men to whom I have referred made his own special individual contribution to the growth of the Institute, but on this occasion I recall especially those former colleagues of mine who laboured hard and long on the Council and its committees; workers such as Eastlake, Brame, Adams, Kewley, and Ashley Carter, to name only a few. Fortunately, some of the early workers are still with us, notably Dr Dunstan and Mr Sell. The Institute is fortunate in having on the Council a number of workers like those I have mentioned. Their work, like all good things, would seem to be its own reward, and yet it is fortunate that one cannot give the best years of one's life to the Institute without the Institute in return giving one the best years of one's life.

I have been very fortunate indeed in the colleagues, technical and administrative, with whom I have been associated throughout my career. I am deeply grateful to them, and I am delighted to see that several are present at this meeting.

Petroleum technology might be likened to a tree with many branches, although it might be more fitting to regard geology not as a branch, but rather as that important part of the tree which is embedded in the earth. Geology is wide in its scope, and its connexions with other sciences are indicated by the very names: geophysics, geochemistry, palæobotany, palæontology and, of course, geology is the

skeleton of geography. It is not only of great economic importance, but in its broader aspects it has a high cultural, and even a philosophical, value. However, I must not dilate on the subject of geology, but return to the Institute, and, sir, I avow myself an optimist regarding the future of the Institute. The past is the best guide to the future, and when one reflects on the wonderful progress that has been made during a comparatively short and a most difficult period, which has included two world wars and the most severe economic blizzard in history, then it would seem that nothing can check the further growth and usefulness of the Institute and that it will go on from strength to still greater strength.

I again thank Council for this award, and trust that the future may provide opportunities for me to be of some service to the Institute which has been, is now, and always will be, my spiritual home.



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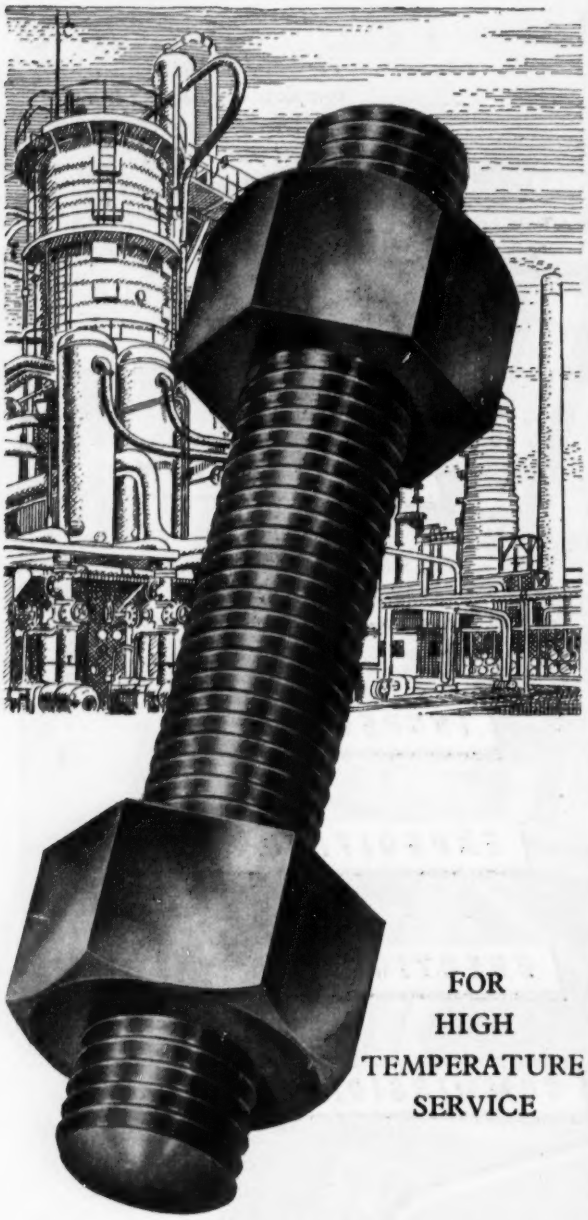

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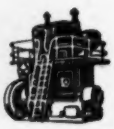

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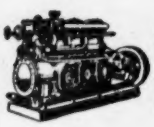

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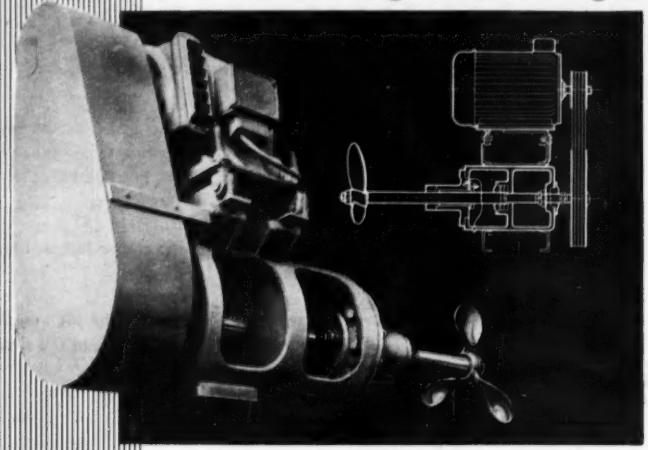

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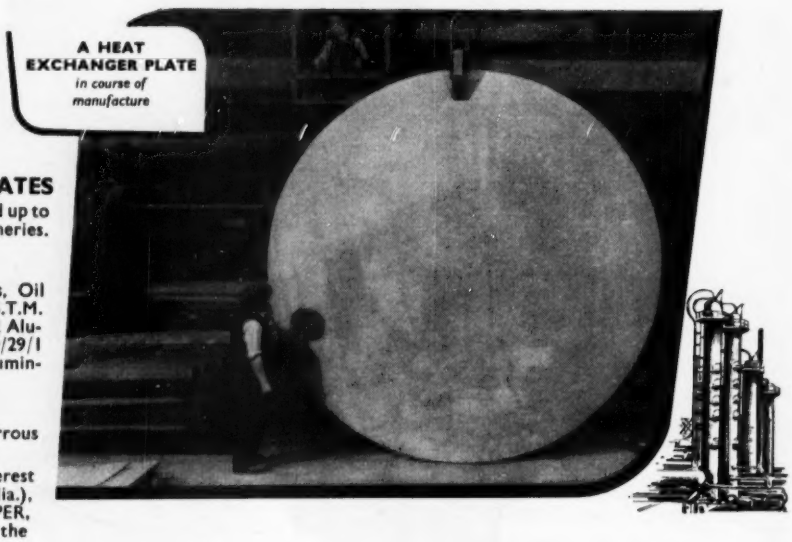

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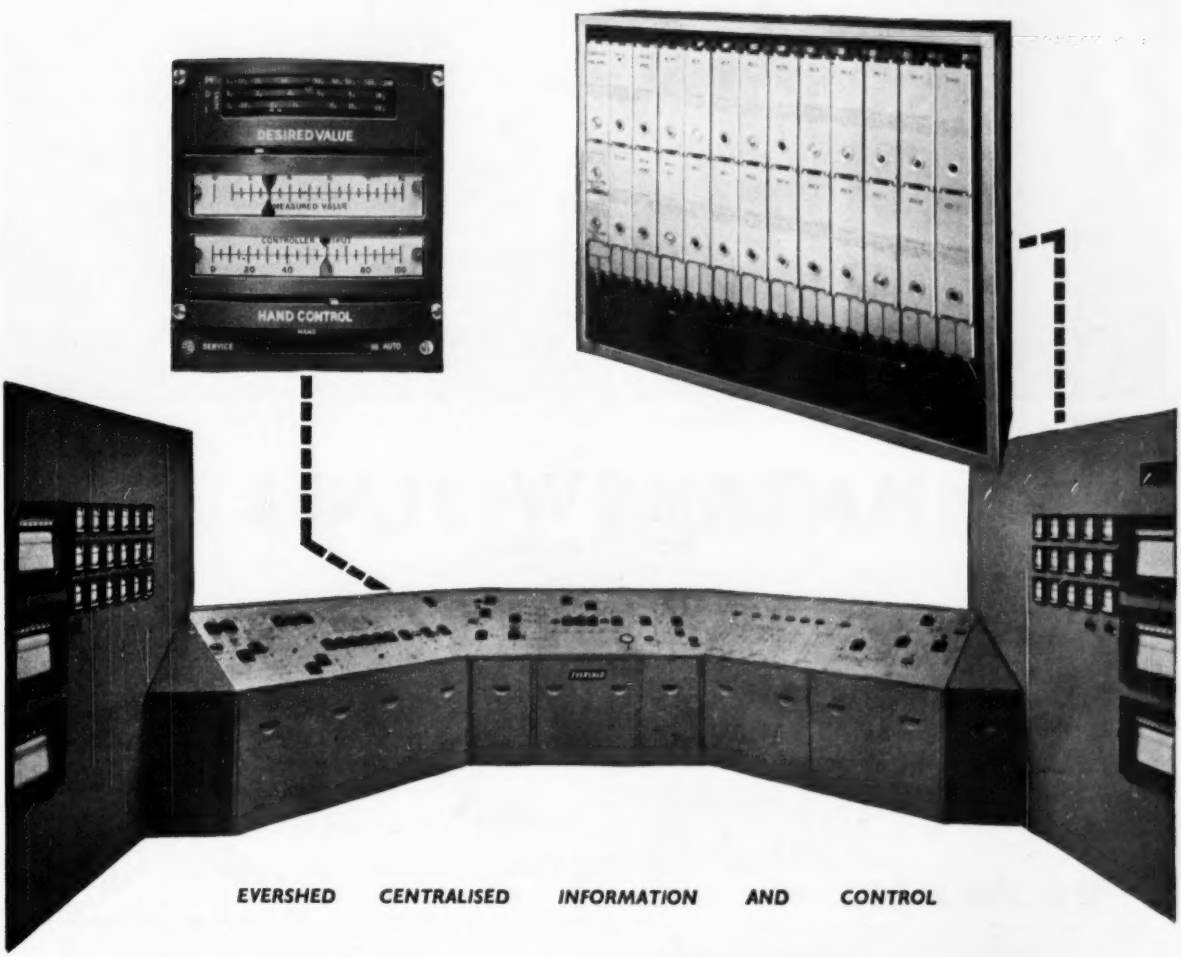

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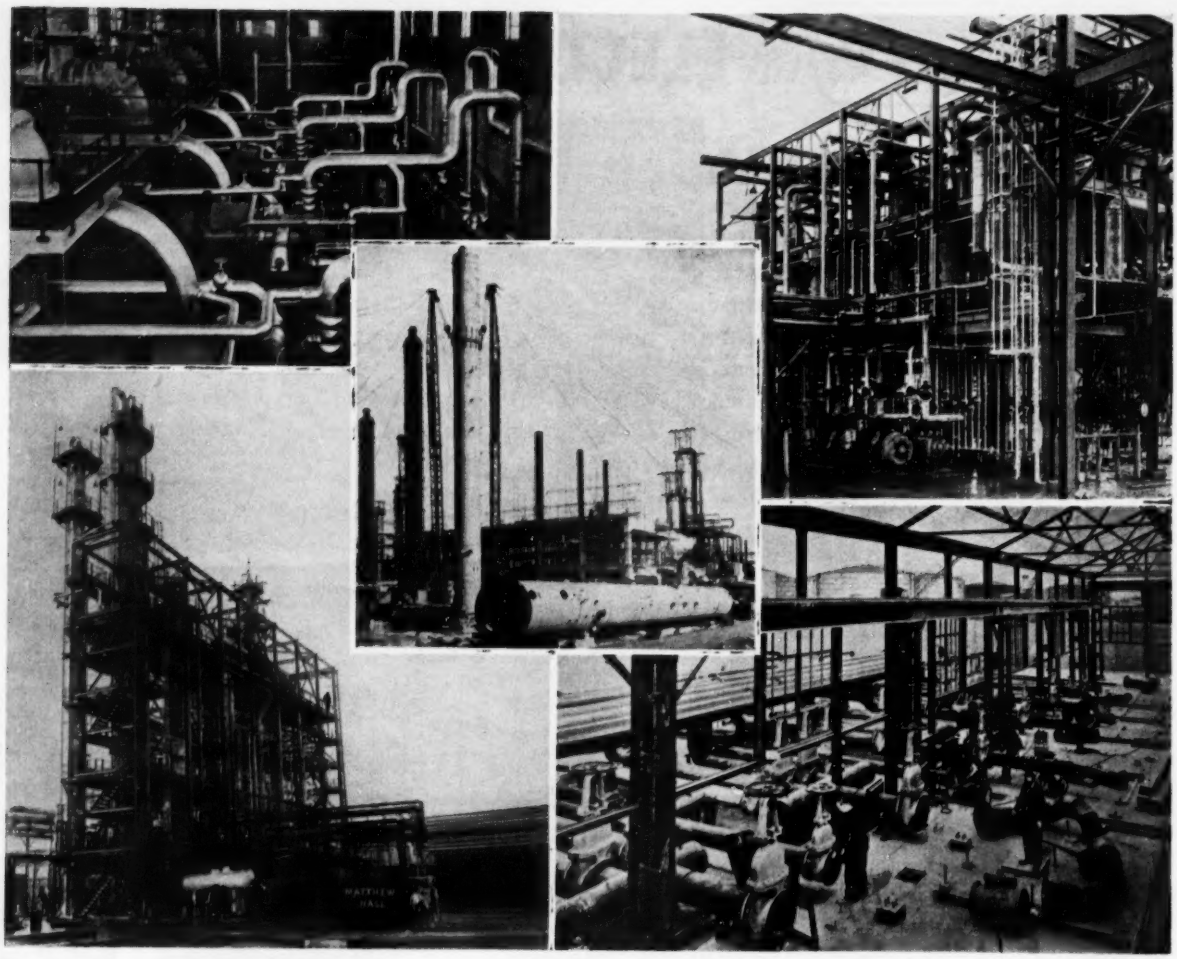

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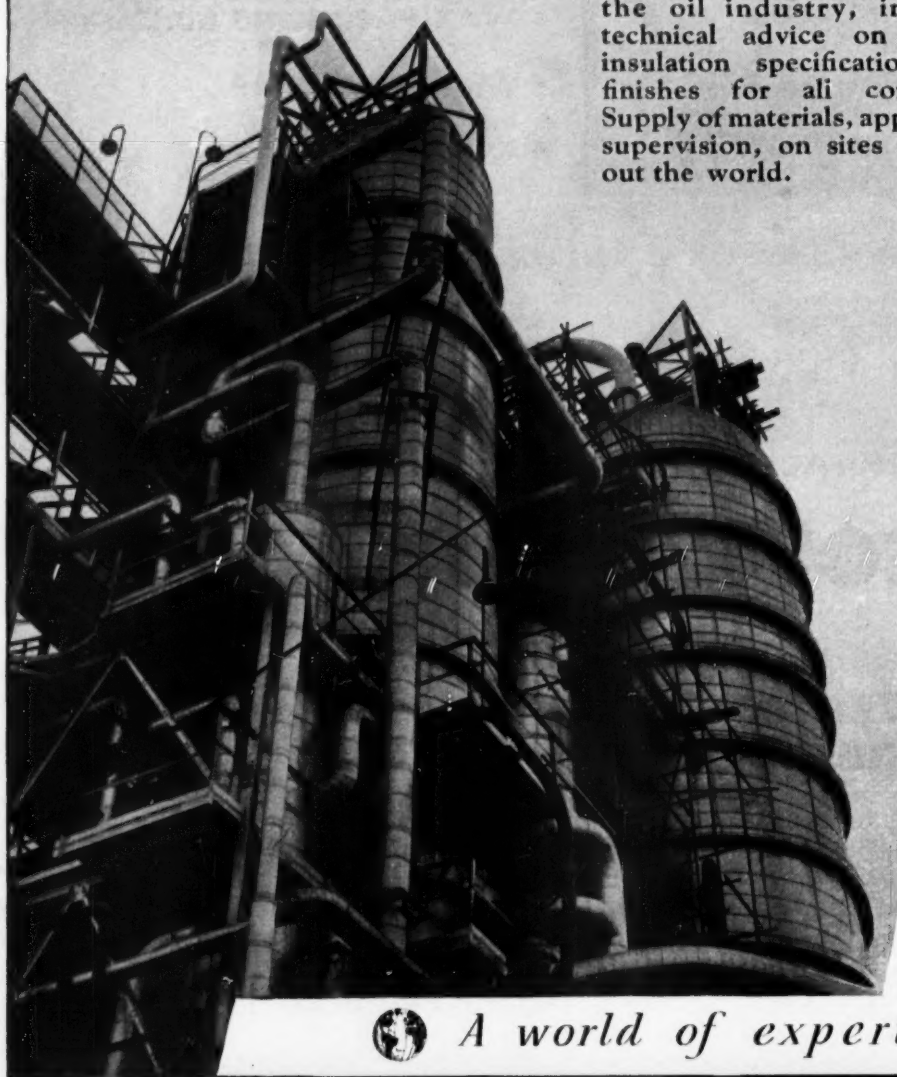

Two Stage Distillation Unit

Photograph by courtesy of The Vacuum Oil Company, Coryton Refinery

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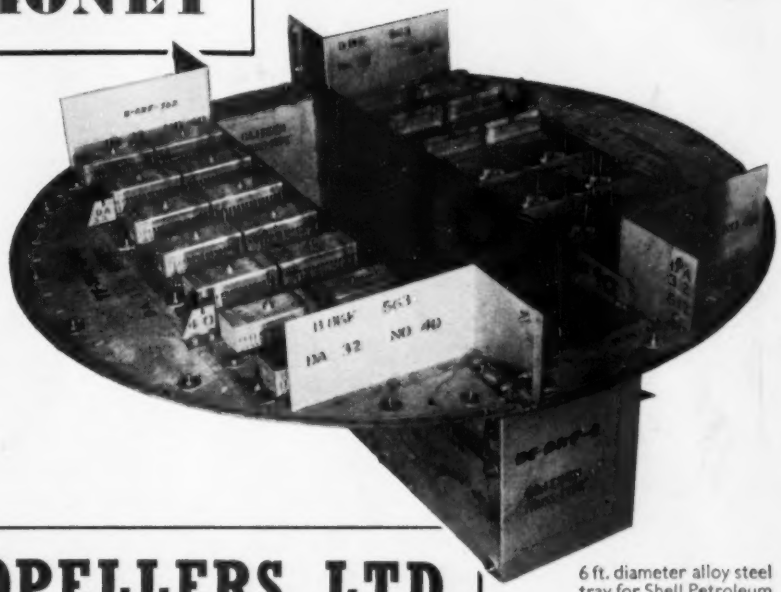

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600-barrel UOP Platforming unit installed at R. J. refinery near Princeton, Ind.

PLATFORMING CHANGES MARKETING METHODS OF R. J. OIL & REFINING CO.

By Henry P. Smith, President
R. J. Oil & Refining Company, Inc.

HIGH quality products being produced in our new UOP Platforming unit have given R. J. new stature in its marketing area and have brought about sweeping changes in marketing techniques.

Henry P. Smith

Before the Platforming unit went on stream at our refinery near Princeton, Ind., R. J. sold premium and regular gasolines at prices lower than those posted at the wholesale outlets of other oil companies.

Now, because R. J.'s gasolines have the highest octane ratings of any in our marketing area, we are commanding prices on a par with those of other companies. And a new theme song—"Fill 'er up and feel the difference"—is being chanted by motorists patronizing our stations.

Motorists are enthusiastic in their praise of the new "Platolene" premium gasoline and "500" regular—both products of the UOP Platformer.

Gasoline sales have nearly trebled since September 5, 1953, when the Platforming unit went on stream. A credit card system was established recently, and already 200 motorists in the 100-mile area R. J. serves have availed themselves of this service.

First Standard "A" Unit

The process design for the Platforming unit was handled by Universal Oil Products Company engineers. All of the mechanical design and drafting, purchasing, and construction were handled by Procon Incorporated. The unit is the first "package" installation of a Standard "A" UOP Platforming process unit.

The decision to install the Platforming unit was made after careful investigation convinced R. J.'s management that it was the ideal catalytic reforming process which would enable the company to become a leader in a marketing area where the race for higher octanes was constantly increasing.

Other factors which motivated our decision were:

—We felt that Platforming would give R. J. a more marketable product.

—We were convinced R. J. could abandon its below-market price policy because of high quality products without suffering a loss in sales.

—We believed that a Platforming unit would give the refinery sufficient flexibility so that the company could always stay on top in the octane race.

—UOP's long record of giving service to licensees.

R. J.'s Platforming unit is equipped with a desulphurizer. Raw charge consists of 400° F. straight run gasoline which goes from storage to a heater, the desulphurizer and then to a prefractionating column.

A cut of approximately 270° F. end point is removed overhead from the prefractionator. The reactor charge, taken as a sidecut from the prefractionating column, is of 400° F. end point material. The sidecut goes from the reactor charge pump through three heaters and reactors.

Recycle Gas Through Reactor

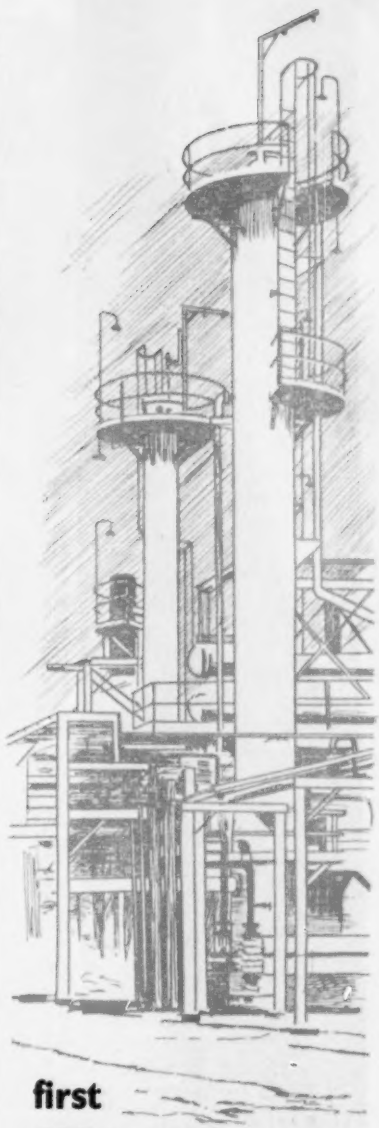
After passing through the No. 3 reactor, the material is sent to a products separator. The compressor takes suction from the top of the separator and recycles the gas through the reactor section.

The liquid bottoms product from the separator is charged to the stabilizer together with overhead material from the prefractionator. Stabilizer effluent is pumped to storage as marketable products.

Sulphur content of the charge stock is converted in the desulphurizer into H_2S, which in turn is removed from the prefractionator in a net overhead cut. The H_2S is removed overhead when this cut is charged to the stabilizer. Gas from the stabilizer is sent to a gas balance drum before being injected into the refinery fuel gas system.

R. J. has spent nearly $1,000,000 to bring to its motoring public the finest gasoline that can be produced. Because of the increasing demand for our gasoline and other products, we are contemplating an extensive expansion programme. Present plans call for doubling the size of the Platforming unit from its present 600 B/SD capacity. It is hoped that this expansion programme will be completed by late 1954 or early 1955.

It is our firm belief that Platforming has made R. J. an increasingly important factor in the economic life of southwestern Indiana, and that the company will continue to grow and prosper because of the superior quality of its products made possible by Platforming.



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UOP Platformer
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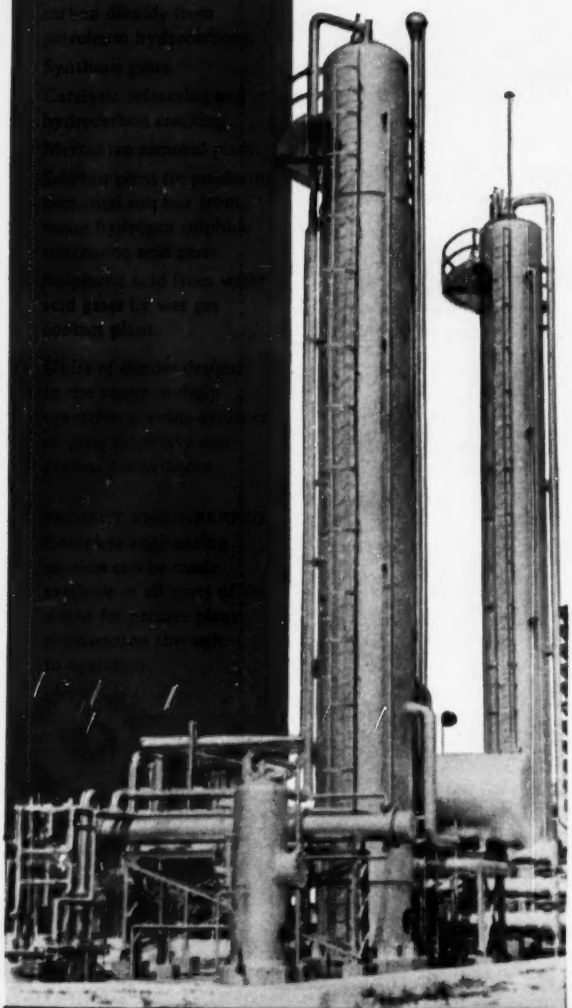

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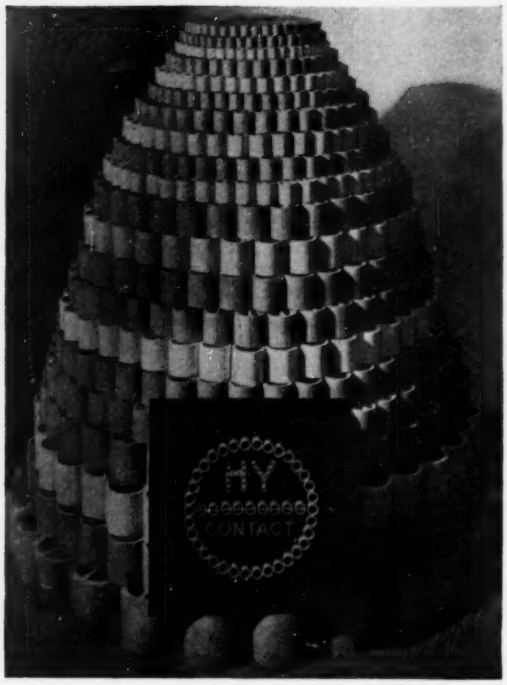

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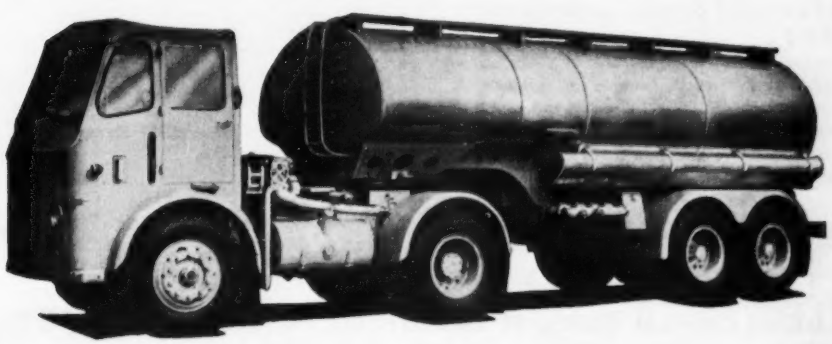

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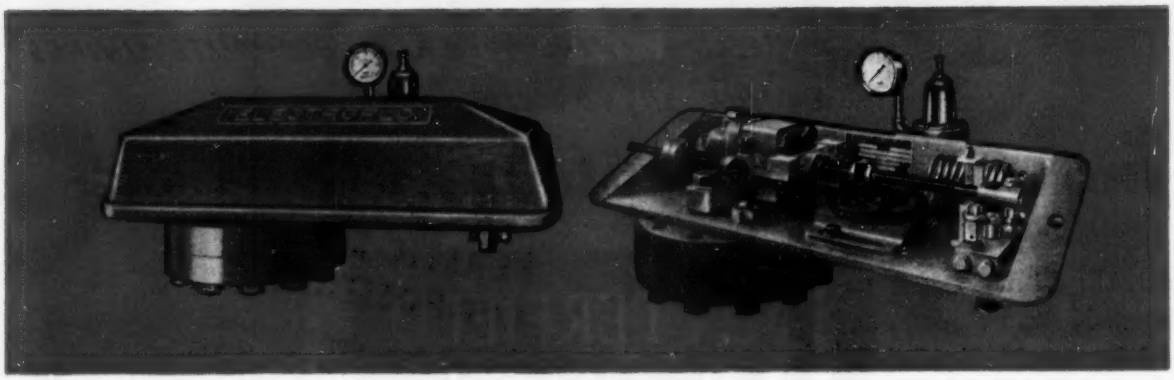

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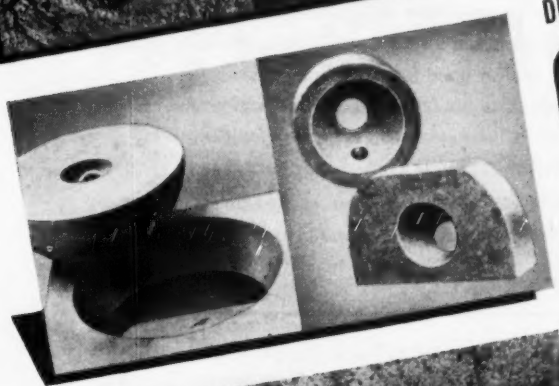

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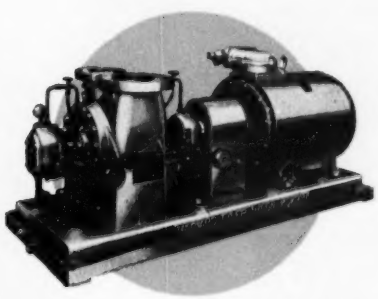

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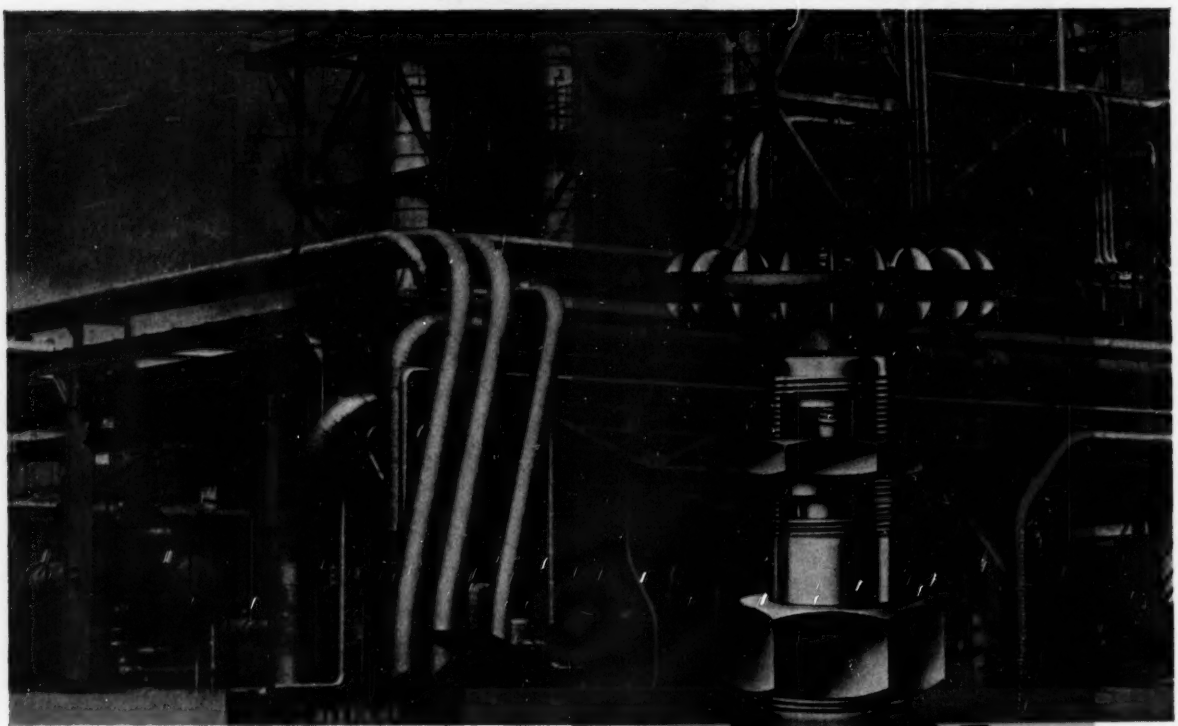
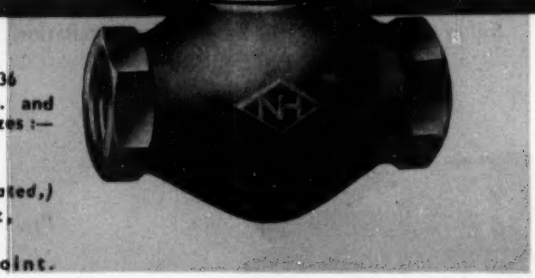
Regularly supplied to the PETROLEUM INDUSTRY

NEWMAN-HENDER *valves*

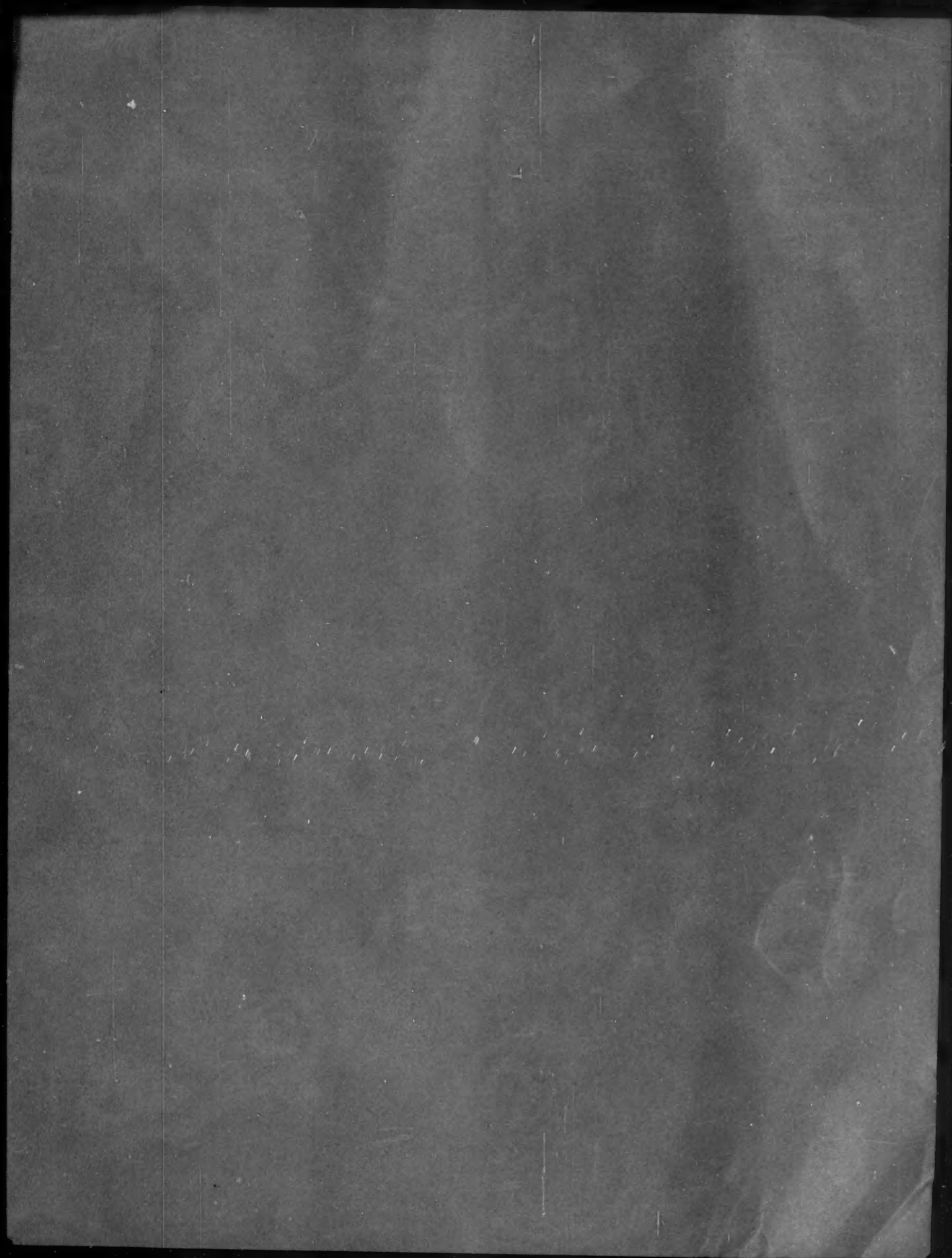


A SHELL PHOTO

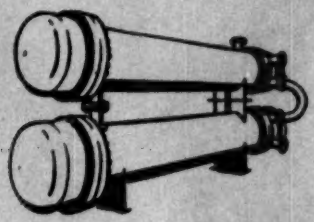
FORGED STEEL GATE VALVE. No. 1636
Available for Working Pressures of 600 lbs. and 900 lbs. at 900° Fahr. and in the following sizes :—
¼", ⅜", ½", ¾", 1", 1¼", 2".
Alternative ends as follows can be supplied :
Screwed Ends Ball Joint *(illustrated,)*
Socket Weld Ends Ball Joint,
Screwed Ends Gasket Joint,
Socket Weld Ends Gasket Joint.

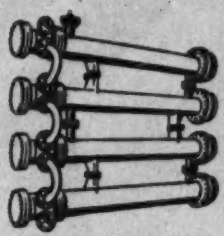


Newman, Hender & Co. Ltd
WOODCHESTER GLOS. ENGLAND



THE CRAIG COMPREHENSIVE SERVICE . . . .





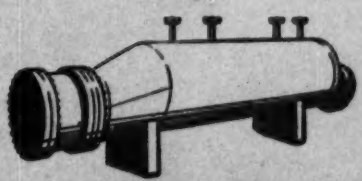
ATMOSPHERIC AND VACUUM DISTILLATION UNITS

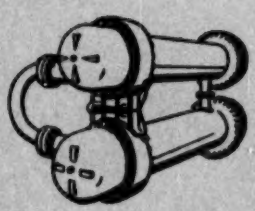
COMBINED DISTILLATION CRACKING, REFORMING AND VAPOUR PHASE TREATING UNITS

PRESSURE DISTILLATE RE-RUN UNITS

GASOLINE RECOVERY AND STABILISATION UNITS

FRACTIONATING COLUMNS AND TUBE STILLS





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PAISLEY SCOTLAND

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